Final Report for Determining Site-Specific Uses and Criteria within the Tidally Influenced Portions of Tres Palacios River and Garcitas Creek

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LIST OF ACRONYMS

AWRL	Ambient Water Reporting Limit
ADCP	Acoustic Doppler Current Profiler
ADV	Acoustic Doppler Velocimeter
CFR	Code of Federal Regulations
COC	Chain of Custody
CRP	Clean Rivers Program
DO	Dissolved Oxygen
EMAP	Environmental Monitoring and Assessment Program
EPA	Environmental Protection Agency
ESRI	Environmental System Research Institute, Inc
LCRA	Lower Colorado River Authority
LCS	Laboratory Control Standard
LCSD	Laboratory Control Standard Duplicate
LIMS	Laboratory Information Management System
MDL	Method Detection Limit
MDM&A	Monitoring Data Management and Analysis
MPN	Most Probable Number
OPRR	Office of Permitting, Remediation, and Registration
PSU	Practical Salinity Units
QA/QC	Quality Assurance/Quality Control
QAM	Quality Assurance Manual
QAO	Quality Assurance Officer
QAPP	Quality Assurance Project Plan
QAS	Quality Assurance Specialist
QMP	Quality Management Plan

RPD	Relative Percent Deviation
RWA	Receiving Water Assessment
SOP	Standard Operating Procedure
SWQM	Surface Water Quality Monitoring
SWQMP	Surface Water Quality Monitoring Procedures
TAMU-CC	Texas A & M University Corpus Christi
TDS	Total Dissolved Solids
TMDL	Total Maximum Daily Load
TCEQ	Texas Commission on Environmental Quality, formerly the Texas Natural Resource Conservation Commission
TOC	Total Organic Carbon
TPWD	Texas Parks and Wildlife Department
TRACS	Texas Regulatory and Compliance System
TSS	Total Suspended Solids
TSWQS	Texas Surface Water Quality Standards
TWDB	Texas Water Development Board
UAA	Use Attainability Analyses
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
VSS	Volatile Suspended Solids

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EXECUTIVE SUMMARY

Tidal streams are highly productive transitional areas between the freshwater of the rivers and the saltwater of the bays. Tidal streams serve as nurseries for many fish and shellfish, including many important commercial and recreational species. Routine monitoring of several tidal streams have revealed dissolved oxygen measurements which are not meeting state water quality standards. Water quality management of these streams has been difficult because there are currently no state-wide criteria for assessing tidally influenced waterbodies, and these systems are naturally quite variable over space and time. The purpose of this study was to collect data in support of the development of a standardized methodology for assessing ecosystem health and assigning site-specific uses and criteria within tidally influenced portions of streams

This study proposes a new methodology which relies heavily on multivariate ordination techniques. This methodology will be further used in assessing the Use Attainability for three tidal segments currently not meeting dissolved oxygen criteria, and therefore potentially not supporting aquatic life uses: Cow Bayou Tidal (Orange County), Tres Palacios River Tidal (Matagorda County), and Garcitas Creek Tidal (Jackson and Victoria Counties). A reference stream approach was used to frame this study; therefore two additional streams were added to the study design – Lost River and West Carancahua Creek. Cow Bayou and Lost River are addressed in a separate document.

Tres Palacios River tidal, Segment 1501, is defined as extending upward from the bay about twelve miles to one mile upstream of the confluence with Wilson's Creek. The tidal portion of Garcitas Creek, Segment 2453A, extends from the bay just upstream of its confluence with Arenosa Creek. West Carancahua tidal, Segment 2456, was ultimately chosen as the reference stream for both Tres Palacios and Garcitas Creek. It is physically located between Tres Palacios and Garcitas Creek, with all three draining into different portions of Matagorda Bay. It exhibits similar land cover/land use patterns, is hydrologically of comparable size, and supports a terrestrial community similar to the two study streams.

The three streams were sampled for two years twice seasonally during the spring, summer and fall for chemical (water quality parameters including physiochemical profiles; short term 24 hour datasonde deployments; long term physiochemical profiles; and water and sediment samples); physical (instream flow; landcover/land use analysis; and instream and riparian habitat classification) were conducted once during the study and biological (nekton sampled with bag seines, trawls and gill nets; sediment and benthic macroinvertebrate/infaunal; as well as aquatic insects) components of ecosystem health. Multiple sampling stations on each stream encompassed the transitional character of the entire tidally influenced ecosystem, from the freshwater of the river to the saltwater of the bay.

Little differences in the physical, chemical, or biological structure were found to exist between the reference stream and either of the study streams. The greatest degree of difference in indicators of ecosystem health all involved upstream – downstream gradients that appear to be driven by salinity structure (the upper and middle stations were similar and significantly different from the lower station). These salinity-driven gradient conditions cut across all of the levels of ecological integrity that were measured for this study.

Based on the results of this study, dissolved oxygen concentration does not appear to be one of the major structuring factors in the physical, chemical, or biological components of ecosystem health.

The analysis techniques applied to the salinity-mediated differences found in this study were equivocal; all the measures of ecosystem health on the study streams were very similar to the reference stream. As such, no Biocriteria for Tidal Streams could be developed that would have applicability over large spatial scales.

This study has shown that no clear difference could be found between the Exceptional and the High Aquatic Life Use classifications. Whether the Exceptional designation of Tres Palacios is too high or the High designations of Garcitas Creek and Carancahua Creek are too low will ultimately depend upon the incorporation of additional datasets into a coast-wide MDS ordination.

INTRODUCTION

Tidal streams are highly productive transition areas between freshwater and saltwater of the bays. Tidal streams serve as nurseries for many fish and shellfish, including important commercial and sport species. Estuarine dependant fish constitute more than 95 percent of the commercial fishery harvests from the Gulf of Mexico, and many important recreational fishery species depend on estuaries during some part of their life cycle (USEPA 1999).

Problem Statement

Both Tres Palacios River Tidal and Garcitas Creek Tidal are currently considered impaired due to depressed dissolved oxygen levels (Draft Texas 303(d) List 2004), although for each of these water bodies, the Texas Commission on Environmental Quality (TCEQ) has indicated that a review of the water quality standards needs to be conducted before a Total Maximum Daily Load (TMDL) is scheduled.

Water quality standards include designated uses for a water body, specific numerical criteria for certain water quality parameters, and narrative criteria (Table 1). The Texas Surface Water Quality Standards (TSWQS) are set by the TCEQ and approved by the United States Environmental Protection Agency (USEPA). The TCEQ has established aquatic life uses and associated criteria for all waters of the state. The numeric criterion for dissolved oxygen is a surrogate or indirect measure of whether the aquatic life use is being maintained. Adequate dissolved oxygen is necessary for a healthy aquatic community. Most aquatic organisms become stressed if oxygen levels below ~2 mg/l persist for prolonged periods.

Table 1. Aquatic Life Use subcategories, and the descriptive measures currently used to assess ecosystem health.

Aquatic Life Use Subcategory	Dissolved Oxygen Criteria, mg/L for Saltwater mean/minimum	Habitat Characteristics	Species Assemblage	Sensitive Species	Diversity	Species Richness	Trophic Structure
Exceptional	5.0/4.0	Outstanding natural variability	Exceptional or Unusual	Abundant	Exceptionally high	Exceptionally high	Balanced
High	4.0/3.0	Highly diverse	Usual association of regionally expected species	Present	High	High	Balanced to slightly imbalanced
Intermediate	3.0/2.0	Moderately diverse	Some expected species	Very low in abundance	Moderate	Moderate	Moderately imbalanced
Limited	<2.0	Uniform	Most regionally expected species absent	Absent	Low	Low	Severely imbalanced

The ability of a water body to support a desired use is an integral consideration in the state and federal water quality standards review and revision process. When a water body is not capable of attaining all the uses included in Section 101(a)(2) of the Clean Water Act or where the level of protection necessary to achieve those uses is not being or cannot be met, 40 CFR Part 131 provides a scientific procedure to select and apply segment-specific use criteria. The procedure, known as a use attainability analysis, is consistent with the intent of Sections 26.023 and 26.026 of the Texas Water Code. The regulation specifies that one or more of the following six conditions may be used for determining if a designated use is unattainable:

1. Naturally occurring pollutant concentrations prevent the attainment of the use; or
2. Natural, ephemeral, intermittent or low flow conditions or water levels prevent the attainment of the use, unless these conditions may be compensated for by the discharge of a sufficient volume of effluent without violating State water conservation requirements to enable uses to be met; or
3. Human caused conditions or sources of pollution prevent the attaining of the use and cannot be remedied or would cause more environmental damage to correct than to leave in place; or
4. Dams, diversions or other types of hydrologic modifications preclude the attainment of the use, and it is not feasible to restore the water body to its original condition or to operate such modification in a way that would result in the attainment of the use; or
5. Physical conditions related to the natural features of the water body, such as the lack of a proper substrate, cover, flow, depth, pools, riffles, and other factors, unrelated to water quality, preclude attainment of aquatic life protection uses; or
6. Controls more stringent than the technology-based requirements established by Section 301(b) and 306 of the Act would result in substantial and widespread economic and social impact. [40 CFR 131.10(g)].

Objectives

The purpose of this study was to collect data in support of the development of a standardized methodology for assessing ecosystem health and assigning site-specific uses and criteria within tidally influenced portions of streams. It is proposed that this methodology will be further used in the preparation of Use Attainability Analyses (UAA) for three tidal segments: Cow Bayou Tidal (Orange County), Tres Palacios River Tidal (Matagorda County), and Garcitas Creek Tidal (Jackson and Victoria Counties). Cow Bayou will be addressed in a separate document.

The work was performed by Texas Parks and Wildlife Department (TPWD) under contract with the TCEQ. Funding for the contract is from the USEPA. Under the contract, TPWD Coastal Fisheries Division staff, led by the Science and Policy and Water Resources Branches, collected data on five tidal streams.

Numerous tidal streams are included on the state's list of impaired waters. Inclusion on this list initiates the TMDL process. As a first step in the TMDL, it is necessary to assess the water body and determine if the impairment is genuine, and if so, whether or not it is caused by pollutants. This task is more difficult with respect to tidally influenced portions of streams, because there is no generally accepted methodology for performing this assessment. The TCEQ and TPWD have jointly recognized the need for developing a scientifically valid methodology for assessing the overall ecosystem health of tidal streams. The data collected as part of this project will ultimately be used to help make recommendations regarding the appropriate aquatic life uses currently identified for classified as well as the numerous unclassified tidal streams. In addition, these data will also be instrumental in the use attainability analysis reports of those impaired streams currently on the 303(d) list.

Study Area

Garcitas Creek Tidal

Description of Water Body and Designated Uses and Criteria

Garcitas Creek, TCEQ segment 2453A, originates in De Witt County, flows through Victoria County, and eventually forms part of the boundary between Victoria and Jackson Counties before emptying into Lavaca Bay. The tidally-influenced portion of the stream extends just upstream of its confluence with Arenosa Creek.

Garcitas Creek Tidal is an unclassified tributary of Lavaca Bay, Segment 2453, referred to as Segment 2453A. As such, it has a presumed high aquatic life use (Texas Natural Resource Conservation Commission 2000b: 30 TAC §307.4(h)(3)). The dissolved oxygen criteria for a tidal water body with a high aquatic life use are: daily average 4 mg/l, and daily minimum 3 mg/l (30 TAC §307.7(b) (3) (A) (i)). The daily average is evaluated as a minimum average across 24 hours. Since most data collected at fixed monitoring stations are instantaneous measurements, direct comparison to the 24-hour criteria is not possible. For Garcitas Creek, 4.0 mg/l is used as the single measurement screening level to evaluate whether the high aquatic life use is being met (TCEQ, 1999a). The dissolved oxygen criteria only apply in the “mixed surface layer,” which in tidally-influenced water bodies is defined as “the portion of the water column from the surface to the depth at which the specific conductance is 6,000 *μmhos*/cm greater than the specific conductance at the surface” (TCEQ, 1999). However, the TSWQS at 30 TAC 307.9(c)(3)(C) also specify that a composite sample from the mixed surface layer be used to determine standards attainment when stratification is caused by temperature (density stratification).

Environmental Features

Twidwell and Davis (1989) described the Garcitas Creek watershed as nearly level to gently sloping. Elevation increases to the north-northwest. Most of the land in the watershed is rangeland, but some cultivation of sorghum, rice, and corn crops also occurs. Commercial production of oil and gas in the area began in the early 1930's and remains important economically. The climate is subtropical humid and annual precipitation averages 38 inches with September being the wettest month. Rainfall is evenly distributed throughout the year, with peaks occurring in the spring due to increased thunderstorm activity and in the fall due to tropical disturbances. Throughout its upper reaches, Garcitas Creek is bordered by narrow wooded belts consisting chiefly of post oak and live oak trees. The canopies of these bordering trees afford substantial shading to creek waters and limit the development of understory vegetation. The trees quickly thin to prairie riparian areas that are utilized for grazing cattle. In the tidally influenced areas of Garcitas Creek, the water is more turbid than the upstream portion and the stream channel is wide and nearly straight. The stream banks are low and heavily wooded; however their canopies do not shade the water surface due to the width of the stream channel. Bottom substrates are nearly uniform, consisting of fine sands. Although the upper banks and riparian areas are heavily wooded, the lower banks are moderately vegetated by coarse grasses, vines, and weeds with many open and broken down areas.

Permitted Discharges

There are no point source discharges emptying directly into Garcitas Creek. There is a small community near the mouth of Garcitas Creek, although it relies on septic systems for domestic wastewater treatment. Because no established uses have been designated for Garcitas Creek Tidal, the presumed high aquatic life use criteria and corresponding dissolved oxygen criteria as indicated in 30 TAC §307.7(b)(3)(A)(ii) are used.

Summary of Historical Data

TCEQ's predecessor agencies conducted two studies which included assessments of Garcitas Creek Tidal. The studies were focused on assessing aquatic life uses of smaller, unclassified streams. The earlier work (Twidwell and Davis 1989) was a pilot study of six unclassified streams selected to represent different ecoregions in Texas. Garcitas Creek was sampled both in the tidal reach and above tidal. Good water quality, including very good dissolved oxygen values, were noted. Other characteristics of the water quality noted during the study included: low levels of oxygen-demanding materials, nutrients, and bacteria. Benthic macroinvertebrates and fish were sampled at two stations in Garcitas Creek, one in the tidal portion and one in the above-tidal portion. Benthic macroinvertebrates were sampled with Surber samplers in riffle areas and Ekman dredges in deeper water. For Garcitas Creek, fish were collected with seining, gill netting, and electrofishing. The communities sampled were evaluated based on indices developed for use in freshwater streams. For the benthic macroinvertebrate data the station in the above-tidal reach was rated exceptional, while the tidal station was rated high. The fish community was rated intermediate to high in the freshwater portion of Garcitas Creek, and high in the tidal portion. The study acknowledged multiple difficulties in attempting to apply the criteria developed for freshwater streams to the tidal portion of Garcitas Creek. The conclusion to the assessment of Garcitas Creek also noted that the habitat quality index developed by the Texas Water Commission (TWC) was not appropriate to use on the estuarine portions of tidal streams. The final assessment was that the aquatic life use for both the freshwater and saltwater portions of Garcitas Creek should be high.

A follow-up study conducted a couple of years later returned to Garcitas Creek (Bowman 1991). The study site was located approximately four miles upstream from Lavaca Bay, and the site was sampled in November, March, May, and August. Dissolved oxygen stratification was noted in May and August, to the extent that bottom water held 0.2 mg/l dissolved oxygen or less. The bottom water was also observed to be more saline. Nekton were collected by cast net, and the sample was dominated by white shrimp and Gulf menhaden. Data showing nekton species and numbers sampled is included in Appendix 1. The author noted that applying some of the metrics used in freshwater assessments (species diversity, species richness, and standing crop) to the nekton community resulted in low scores. However the study concluded that it was well known that tidal streams are extremely productive biologically and important to estuarine systems as nursery areas, and that biological criteria for evaluating tidal streams have not been developed.

Data from these and other studies support the designation of both Garcitas Creek and its tributary, Arenosa Creek, as high to exceptional quality sites for water quality and aquatic life (Bayer et al. 1992). In addition, Garcitas Creek harbors two rare species, the Texas palmetto and diamondback terrapin, and contains extensive estuarine wetland habitat (El-Hage et al. 1999).

Review of Water Quality Data

Water quality data from the Surface Water Quality Monitoring (SWQM) portion of the TCEQ Regulatory Activities and Compliance System (TRACS) database was reviewed for the period of record. The focus was on dissolved oxygen measurements, since low oxygen is the reason this water body was suspected to be impaired.

2000 303(d) Listing of Garcitas Creek Tidal

The data used in the assessment to list Garcitas Creek Tidal as impaired for dissolved oxygen was also reviewed separately. Garcitas Creek Tidal was listed in 2000 for partial support of the aquatic life use. The procedures for evaluating surface water data to determine whether uses and criteria were being met is described in “2000 Guidance for Screening and Assessing Texas Surface and

Finished Water Quality Data" (TCEQ 2000). Under this guidance, dissolved oxygen data from the five-year period of record (1994-1999) was compared to the criterion, to determine whether the aquatic life use was being met. Two types of data could be used to assess use support – instantaneous or routinely collected data and 24-hour or intensively collected data. With instantaneous data, at least nine values were required to evaluate whether the criterion was being met, with use being fully, partially, or not met based on the percentage of measurements not meeting the instantaneous screening level (4.0 mg/l in the case of Garcitas Creek Tidal). With 24-hour data, at least five sets of measurements were required to evaluate whether the criterion was being met. Use attainment was evaluated based on the percentages of means and minimum values from those data sets which met the average and minimum criteria established under the TSWQS.

For the 2000 assessment, 13 dissolved oxygen measurements were evaluated; all were taken at Station 13289, Garcitas Creek at FM 616, 2.2 miles southwest of LaSalle. See Fig. 1 for locations of stations. All were instantaneous measures of dissolved oxygen. Table 2 summarizes the results of the assessment.

Table 2. Summary of Dissolved Oxygen Data and Violations of Criteria Assessed for the 2000 Water Quality Inventory and 303 (d) List.

Station ID	**Mean D.O. (mg/l)**	**N**	**No. Violations**	**(%)**
13289	5.8	13	3	23.1

The three violations prompting the listing were measurements of 3.9 mg/l (taken in October 1996), 2.7 (August 1997), and 3.0 (September 1997). Two were taken during hot months of the year (water temperature was 27.4 degrees C for the August sample and 27.2 for the September sample).

In the 2000 assessment, total phosphorus was also found to be a concern.

Summary of SWQM TRACS Historical Data

A raw data report of all SWQM data on Segment 2453 was obtained for the period of record ending with June 21, 2002. Over the period of record, dissolved oxygen measurements have been collected at only two stations on Garcitas Creek, Station 13289 (at FM 616) and Station 13290 (at FM 444) (Fig. 1).

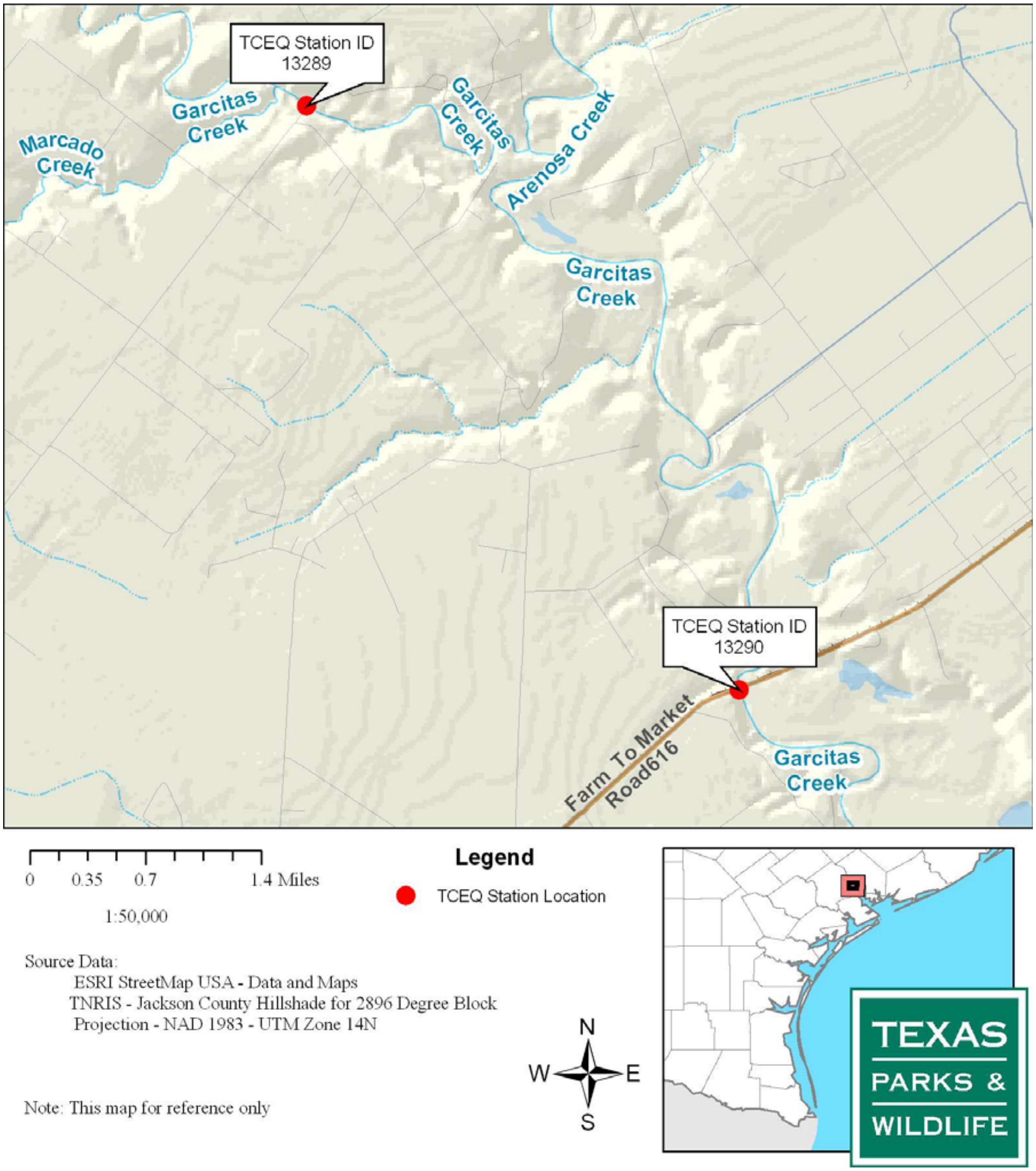


Figure 1. Map of Garcitas Creek Tidal showing TCEQ station locations.

Mixed Surface Layer D.O. Measurements

An analysis was made of instantaneous D.O. measured at 0.3 meters or less from the surface (to approximate the mixed surface layer). Data collected between 5:00 and 9:00 a.m., which approximates the critical early morning period, was removed from the analysis. The mean D.O. for the remaining 54 measurements was 7.3 mg/l, and values ranged from 2.71 to 13.9 mg/l. Table 3 shows the mean D.O. and standard deviations for these data by station. Only three measurements were made at Station 13290.

Table 3. Mean surface (<= 0.3m) Dissolved Oxygen Measurements for Period of Record by Station (mean+/- Std. Dev.)

Station	Number of measurements	Mean Dissolved Oxygen mg/L	Range	Standard Deviation
13290 (upstream)	3	6.8	6.1 – 7.4 mg/l	0.67
13289 (downstream)	51	7.3	2.7 - 13.9 mg/l	2.12

Critical Early Morning

The data set contained only two measurements collected from 5:00 to 9:00 a.m. The values were 5.7 mg/l at Station 13290 and 7.1 mg/l at Station 13289. Both measurements were made in August 1987. These values represent good oxygen levels for the early morning.

Vertical Profiles

Data from only two sampling events was available to evaluate vertical profiles of dissolved oxygen and specific conductivity, both at station 13289. In October 1973 a profile revealed that the water column was well-mixed and quite fresh. Dissolved oxygen was good throughout the water column (Table 4). In August 1989 conditions were much more saline at station 13289, and higher conductivities at depth revealed that a salt wedge was present (Table 4). Dissolved oxygen decreased dramatically as depth increased, such that the water column was practically anoxic below 3 meters.

Table 4. Vertical profiles Garcitas Creek Dissolved Oxygen and conductivity for 17 October 1973 and 7 August 1989.

Date (MM/DD/YY)	Time	Depth (M)	Specific Conductance (µmhos/cm)	Dissolved Oxygen (mg/L)
10/17/1973	13:00	0.30	170	5.3
10/17/1973	13:00	3.05	175	5.5
08/07/1989	15:56	0.30	11,200	9.7
08/07/1989	15:56	1.52	13,580	6.4
08/07/1989	15:56	3.05	20,900	0.2
08/07/1989	15:56	4.27	22,600	0.1

Trends Over Time

Data from the mixed surface layer (measured at 0.3 meters or less from the surface) and collected anytime other than the critical early morning period (5:00 – 9:00 a.m.) was plotted for Station 13289 (Fig. 2). Data collection was not continuous over time, with most data points collected in the 1970s, late 1980s, and late 1990s.

Effects of Nutrients, Suspended Solids, and TOC on Dissolved Oxygen

TRACS data were requested for sampling events where nutrients (ammonia, nitrate, phosphate), total suspended solids (TSS) and total organic carbon (TOC) were measured along with dissolved oxygen. For Station 13289 the correlation between each of these parameters and dissolved oxygen was evaluated (Table 5). Dissolved oxygen decreased as TOC and phosphate increased. However D.O. increased with increasing ammonia as well. There was no discernable trend with nitrate or TSS. For a more detailed report please refer to Contreras (2003b).

Table 5. Pearson correlation coefficients between various water quality parameters and dissolved oxygen.

	TSS	TOC	NH4	PO4	NO3
Correlation coefficient (r)	0.059	-0.747*	0.520*	-0.587*	-0.012
Sample size (n)	36	15	30	20	34

r : used to quantify the strength of the association between the variables. While positive r values indicate both increase together, negative r values indicate a negative relationship.
*: p values < 0.05, hence one variable can be used to predict the other variable.

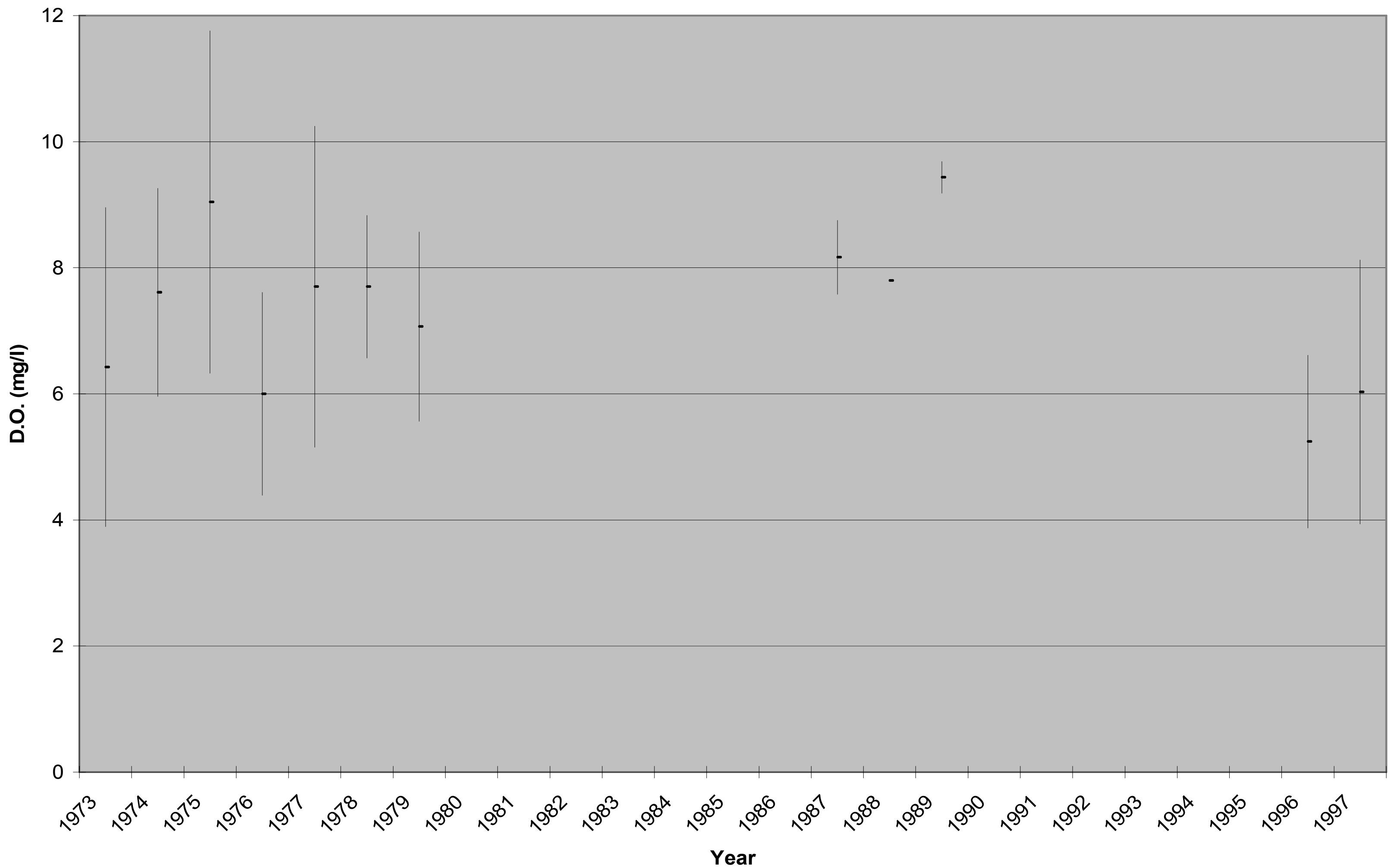


Figure 2. Mean Dissolved Oxygen at Garcitas Creek Station 13289 (+/- Std. Dev.).

History of Fish Kills and Spills

TPWD maintains a database on major reported kill and spill events in Texas. That database was queried for the period of record and a summary is shown in Table 6.

Table 6. TPWD fish kill event data for Garcitas Creek tidal.

Event	Date	Source/Cause	Location	County	Segment	Number Killed
Fish kill	18 May 1981	Dumping of illegal nets	Lavaca Bay	Calhoun	2453	<100
Fish kill	30 May 1996	Catfish virus	Lavaca Bay Palacios Creek to Garcitas Cove	Jackson	2453	3500
Fish kill	18 May 2004	Seismic	Matagorda, Lavaca, Chocolate, Cox, Keller & Carancahua Bay	Calhoun	2456,2455 2454,2453 2451	28,289

Garcitas Creek Conclusion

There is a limited water quality data set for Garcitas Creek Tidal. The segment was listed as impaired based on only three violations of the criterion, the lowest value of which was 2.7 mg/l. The mean dissolved oxygen for measurements taken within 0.3 meter of the surface over the period of record was 7.3 mg/l, which is very good. Although there were only two values in the database taken during the critical early morning period, both easily met the water quality criterion for dissolved oxygen. The only situation where dissolved oxygen was measured at extremely low levels was measured in August 1989 near the bottom of the water column.

Biological data on Garcitas Creek Tidal indicate a healthy aquatic community. The assessment is hampered by the lack of appropriate evaluation tools for the tidally-influenced portion of Garcitas Creek.

Tres Palacios River Tidal

Description of Water Body and Designated Uses and Criteria

Tres Palacios River originates in Wharton County and flows about 55 miles to Tres Palacios Bay in Matagorda County. The tidal portion of the stream, Segment 1501, is defined as extending upward from the bay about twelve miles, to one mile upstream of the confluence with Wilson Creek.

The designated uses for Tres Palacios River Tidal, Segment 1501, are contact recreation and exceptional aquatic life use (TCEQ 2000: 30 TAC §307.10(1)). The dissolved oxygen criteria for a tidal water body with an exceptional aquatic life use are: daily average 5 mg/l, and daily minimum 4 mg/l (30 TAC §307.7(b)(3)(A)(i)). The daily average is evaluated as an average over a minimum of a 24-hour period. For Tres Palacios River Tidal, 5.0 mg/l is used as the single measurement screening level to evaluate whether the high aquatic life use is being met (TCEQ, 1999a). Because most data collected at fixed monitoring stations are instantaneous measurements, direct comparison to the 24-hour criteria is not possible. The dissolved oxygen criteria only apply in the "mixed surface layer," which in tidally-influenced water bodies is defined as "the portion of the water column from the surface to the depth at which the specific conductance is 6,000 *µmhos*/cm greater than the specific conductance at the surface" (TCEQ, 1999a).). However, the TSWQS at 30 TAC 307.9(c)(3)(C) also specify that a composite sample from the mixed surface layer be used to determine standards attainment when stratification is caused by temperature (density stratification).

Permitted Discharges

There is one permitted wastewater discharge in Segment 1501, Markham Municipal Utility District (Fig. 3). There is also a registered aquaculture facility, Ekstrom Enterprises, which discharges a significant volume of wastewater into Segment 1502, upstream of Tres Palacios River Tidal.

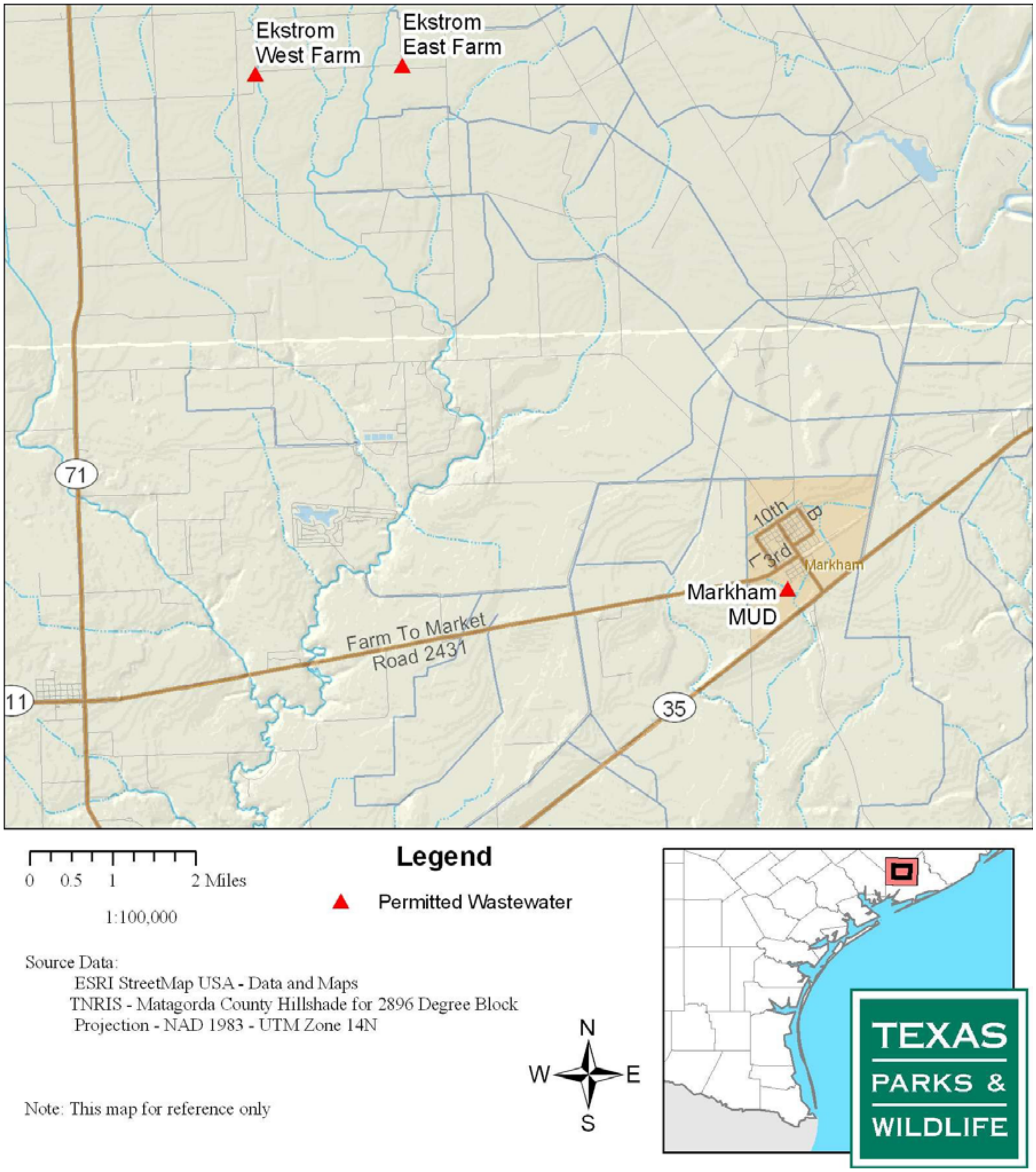


Figure 3. Tres Palacios River Tidal permitted wastewater discharge points.

Summary of Historical Data

There are no previous studies published by TCEQ on Tres Palacios River Tidal. The Lower Colorado River Authority (LCRA), in conjunction with their USEPA funded Clean Rivers Program, has maintained a routine monitoring site on Segment 1501, collecting water quality measurements as well as dissolved metals in water data. During 1998, metals samples were collected using a peristaltic pump with c-flex tubing and in-line disposable 0.45 micron filters. The samples were analyzed for dissolved aluminum, arsenic, barium, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver, and zinc. Dissolved metals, except for mercury, were analyzed using USEPA analytical method 200.8. Mercury was analyzed using USEPA method 7470.A (LCRA 2002). Results of the dissolved metals analysis of water samples are summarized in Table 7 and water quality measurements in Table 8.

Table 7. Metals Results for Dissolved Metals (mg/L) in Water Sampling August 1998 in Tres Palacios at FM 521 segment 1501.

Constituent	**Amount**
Mercury	< 0.2
Aluminum	7.5
Arsenic	6.3
Selenium	95.6
Silver	< 1.0
Barium	192.0
Cadmium	< 1.0
Chromium	19.3
Copper	20.2
Lead	< 1.0
Nickel	26.0
Zinc	< 4.0

On the recommendation of the Clean Rivers Program Steering Committee, a special study was initiated in 1999 to investigate the source of elevated bacterial counts on the Tres Palacios River. This study found that bacterial counts were elevated throughout the river during and approximately one week after rain events strong enough to produce runoff into the river, and nutrient concentrations during dry weather monitoring conditions appeared to be tied to populated areas. Higher levels of nutrients were reported in the upper and lower (Segment 1501) ends of the watershed. In the lower watershed, these elevated nutrient levels could be attributed to housing subdivisions using onsite sewage facilities (LCRA 2002).

Table 8. Summary of Annual Means of Water Quality Results for Tres Palacios River, Station 12515, for 1996 to 2000.

Segment	**Year**	**Constituent**										
		Temp (^{0}C)	**Dissolved Oxygen (mg/L)**	**pH (S.U.)**	**Ammonia (mg/L)**	**Nitrate+ Nitrite (mg/L)**	**Total Phosphorus (mg/L)**	**Ortho Phosphorus (mg/L)**	**Chloride (mg/L)**	**Sulfate (mg/L)**	**E. coli (cfu/dL)**	**Chlorophyll (μg/L)**
1501	1996	21.45	6.73	7.58	0.135	0.626	0.291	0.132	1524.0	207.7	78	3.4
	1997	20.82	6.74	7.48	0.125	1.539	0.400	0.091	255.8	34.0	101	9.0
	1998	23.82	5.63	7.14	0.204	1.475	0.238	0.075	1057.0	407.7	67	5.1
	1999	23.16	6.78	7.58	0.063	1.158	0.220	0.128	4090.1	561.5	48	10.0
	2000	20.33	6.66	7.80	0.205	0.688	0.450	0.173	2368.0	337.9	48	5.1
	Mean	22.01	6.52	7.46	0.148	1.096	0.305	0.119	1770.9	292.6	38	6.6
	Bench mark	35.00	5.00	6.5 - 9.0	0.580	1.830	0.710	0.550	-	-	126	19.2
	Violation Rate %	0.00	23.10	0.00	0.00	9.10	5.60	0.00	0.00	0.00	22.0	25.0

Review of Water Quality Data

Water quality data from the Surface Water Quality Monitoring (SWQM) portion of the TCEQ Regulatory Activities and Compliance System (TRACS) database was reviewed for the period of record. The focus was on dissolved oxygen measurements, since low oxygen is the reason this water body was suspected to be impaired.

2000 303(d) Listing of Tres Palacios River Tidal

The data used in the assessment to list Tres Palacios River Tidal as impaired for dissolved oxygen was also reviewed separately. Tres Palacios River Tidal was listed in 2000 for partial support of the aquatic life use. The procedures for evaluating surface water data to determine whether uses and criteria were being met is the same as was described earlier in this document for Garcitas Creek except the screening level for DO was 5.0 mg/ l.

For the 2000 assessment, 18 dissolved oxygen measurements were evaluated; all were taken at Station 12515, Tres Palacios River Tidal at FM 521 east of Palacios (Fig. 4). All were instantaneous measures of dissolved oxygen. Table 9 summarizes the results of the assessment. The four exceedances prompting the listing were measurements of 4.75 mg/l (taken in September 1993), 2.60 (June 1994), 3.07 (September 1994), and 3.7 (June 1997). All were taken during hot months of the year (water temperatures ranging from 26.7 to 29.3 degrees C).

Table 9. Summary of Dissolved Oxygen Data and Violations of Criteria Assessed for the 2000 Water Quality Inventory and 303(d) List.

Station ID	**Mean D.O. (mg/l)**	**N**	**No. Exceedances**	**(%)**
12515	6.7	18	4	22.2

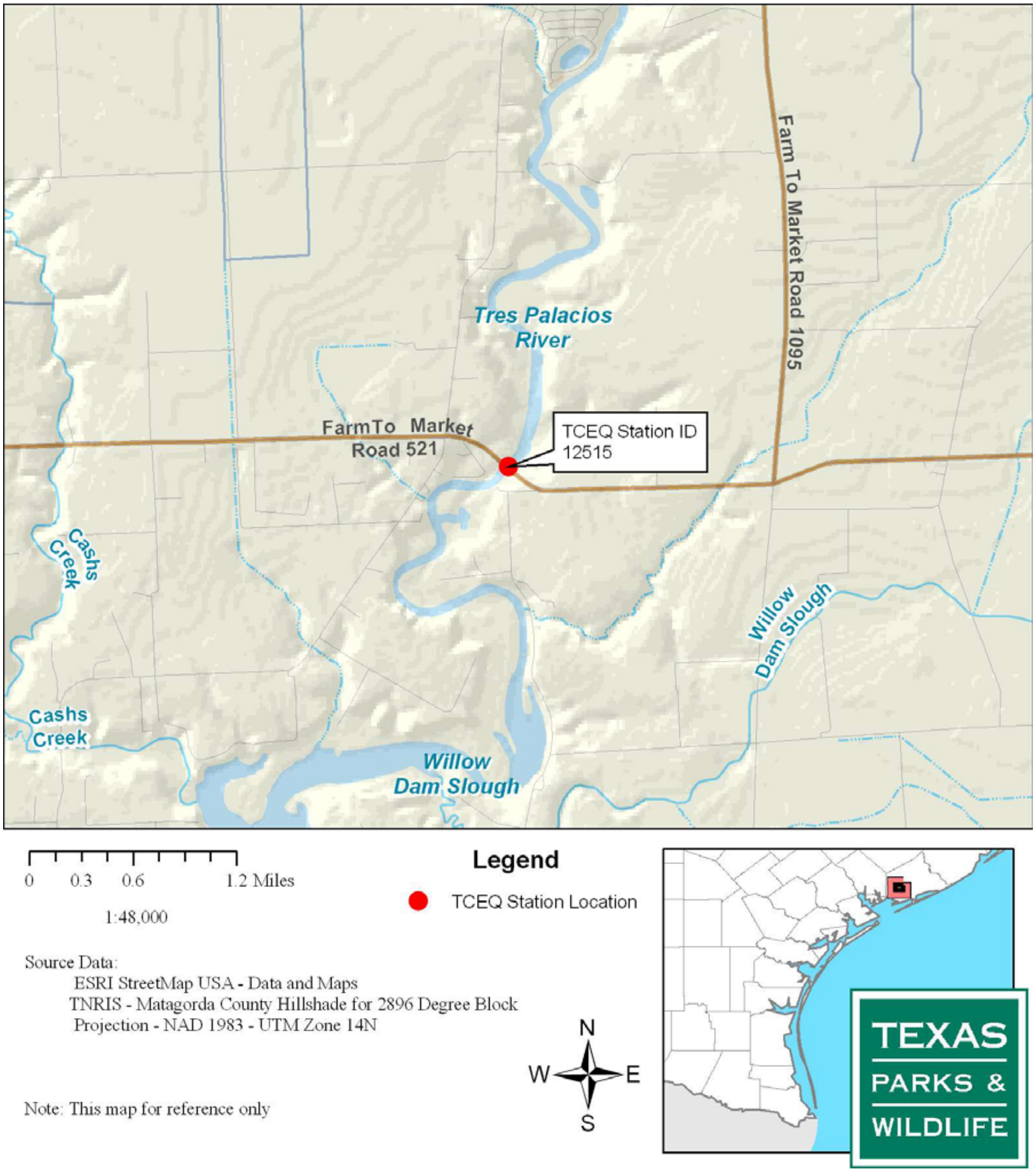


Figure 4. Map of Tres Palacios River Tidal showing TCEQ station location.

Summary of SWQM TRACS Historical Data

A raw data report of all SWQM data on Tres Palacios River Tidal (Segment 1501) was obtained for the period of record ending with June 21, 2002. Over the period of record, water quality data has been collected at only one station, Station 12515.

Mixed Surface Layer D.O. Measurements

An analysis was made of instantaneous D.O. measured at 0.3 meters or less from the surface (to approximate the mixed surface layer). Data collected between 5:00 and 9:00 a.m., which approximates the critical early morning period, was removed from the analysis. The mean D.O. for the remaining 131 measurements was 7.52 mg/l, and values ranged from 2.57 to 16.3 mg/l.

Critical Early Morning

The data set contained only four measurements collected from 5:00 to 9:00 a.m., ranging from 2.33 to 6.76 mg/l.

Vertical Profiles

Summarizing vertical profile data is problematic since data were collected at different depths each sampling trip, depending on the maximum depth at the sampling location that day. Most of the profile data showed a relatively well-mixed water column with little stratification due to salinity. Dissolved oxygen was maintained near or above the water quality standard. One profile exhibited density stratification. Specific conductivity and dissolved oxygen displayed an inverse relationship, with dissolved oxygen levels dropping by almost half in a vertical span of less than 2 meters. For more detailed information see Contreras (2003c).

Trends Over Time

Data from the mixed surface layer (measured at 0.3 meters or less from the surface) and collected anytime other than the critical early morning period (5:00 – 9:00 a.m.) were examined for Station 12515 (Fig. 5). Overall D.O. levels were above 5.0 mg/L. It was difficult to determine whether a trend existed over time, but the graph of the mean D.O. values appeared to oscillate over about a six-year cycle.

Twenty-four Hour Data

The data set included two data points for 24-hour measurements of dissolved oxygen and other conventional parameters. Table 10 depicts the results of two twenty-four hour measurements made at Station 12515. The measurements typically exceeded the average criterion oxygen level, although the minima and maxima imply a fairly strong diel swing in oxygen, which is probably due to instream photosynthesis.

Table 10. Summary of 24-hour measurements made on Tres Palacios River Tidal, Station 12515, at 0.61 meters.

Date	Mean D.O. (mg/l)	Min. D.O. (mg/l)	Max. D.O. (mg/l)
7/8/1998	6.9	2.2	11.5
7/9/1998	6.2	2.2	9.4

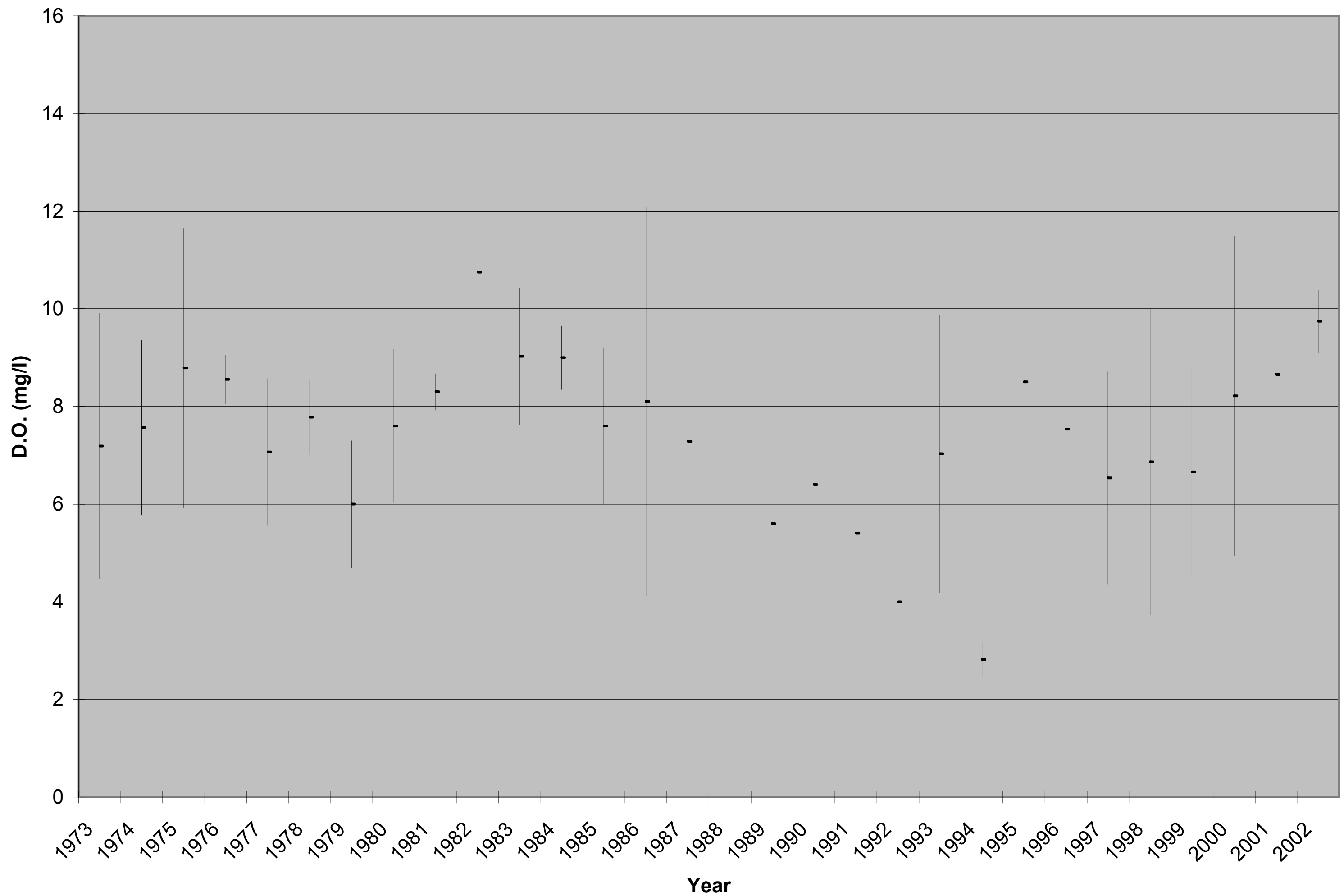


Figure 5. Mean Dissolved Oxygen at Tres Palacios Station 12512 (+/- Std. Dev.)

History of Fish Kills and Spills

TPWD maintains a database on major reported kill and spill events in Texas. That database was queried for the period of record and a summary is shown in Table 11.

Table 11. TPWD fish kill event data for Tres Palacios River tidal.

Event	Date	Source/Cause	Location	County	Segment	Number Killed
Fish kill	05 Sep 2001	Low DO due to recent rainfall event	FM 521 & Tres Palacios River	Matagorda	1501	1000
Fish kill	30 May 1996	Catfish virus	Lavaca Bay Palacios Creek to Garcitas Cove	Matagorda to Jackson	2453, 1501, 2452	3,500
Fish kill	24 Apr 1994	Oil and Brine Released	2.5 miles SW of Vanderbilt (Tres Palacios Tidal)	Jackson	1501	8
Fish kill	10 April 1991	Organic compound (crude oil)	Tres Palacios River tidal (Wilson Creek upstream of FM 1095 bridge)	Matagorda	1501	No count
Fish kill	10 Apr 1989	Crude oil	Tres Palacios River tidal	Matagorda	1501	No Count
Fish kill	26 Aug 1978	Pipeline leaked (brine)	¼ mile south of Eldorado Rd on Kountze-Couch lease	Matagorda	1501	280

Tres Palacios Conclusion

Historical water quality data on Tres Palacios River Tidal shows relatively good water quality in terms of dissolved oxygen. Mean dissolved oxygen values collected within the top 0.3 meter of the water column averaged 7.52 mg/l, which is very good. The lowest value which exceeded the water quality criteria, prompting the listing of the segment as impaired, was 2.60 mg/l. The lowest value recorded during the critical early morning period was 2.33 mg/l. Even these minimum values, while not optimal for aquatic life, are not indicative of severe hypoxic or anoxic conditions.

We did not find any TCEQ-vetted biological data on Segment 1501. Of the three streams being studied under this project, this is the only one for which no biological data was available.

Reference Streams

There are no unimpacted tidally influenced streams in the mid-coast region of Texas. It was difficult to find streams with a similar watershed size, salinity, or riparian and instream habitat. Coastal basin waters investigated but ultimately rejected as suitable reference streams, listed by county, included: the San Bernard River and Cedar Lake Creek (Brazoria County); Caney Creek, Boggy Creek, Live Oak Bayou, Big Boggy Creek, the Colorado River, and Turtle Creek (Matagorda County); Keller Creek, Chocolate Bayou, Coloma Creek, and the Guadalupe River (Calhoun County); East Carancahua Creek, the Lavaca River, and Venado Creek (Jackson County); the Mission River (Refugio County); Cavasso Creek, Copano Creek, and the Aransas River (Aransas County); Chiltipin Creek and the Nueces River (San Patricio County).

After an exhaustive search for suitable reference streams, the west fork of Carancahua Creek (West Carancahua), TCEQ segment 2456, was ultimately chosen as the reference stream for both Tres Palacios and Garcitas Creek. West Carancahua is physically located between Tres Palacios and Garcitas Creek, with all three draining into different portions of Matagorda Bay. West Carancahua Creek rises two miles northeast of White Hall in northeastern Jackson County and runs south for twenty-eight miles to its junction with East Carancahua Creek, at the head of Carancahua Bay in extreme southeastern Jackson County (Handbook of Texas Online, accessed 4/27/2005). The stream is intermittent in its upper reaches where it crosses flat to rolling prairie, surfaced by dark clay that supports mesquite, grasses, and cacti. Downstream, the flat and locally depressed terrain is surfaced by clay and sandy loams that support water-tolerant hardwoods, conifers, and grasses. As the identified reference stream, West Carancahua Tidal exhibits similar land cover/land use patterns, is hydrologically of comparable size, and supports a terrestrial community similar to the two study streams (German 2005).

West Carancahua Creek was sampled by TPWD River Studies in 1988 by seine and backpack electrofisher (Linam et al 2002). Twelve fish species were identified from the sample (Appendix 2). The same year TCEQ and TPWD sampled West Carancahua Creek using a Surber sampler. Thirty-four taxa of benthic invertebrates were identified (Bayer et al 1992). The list of taxa is attached in Appendix 3.

History of Fish Kills and Spills

TPWD maintains a database on major reported kill and spill events in Texas. That database was queried for the period of record and a summary is shown in Table 12.

Table 12. TPWD fish kill event data for West Carancahua Creek tidal

Event	Date	Source/Cause	Location	County	Segment	Number Killed
Fish kill	06 Oct 1980	No known reason	Carancahua Bay, El Campo Beach	Calhoun	2456	<100
Fish kill	07 Oct 1980	Suspected dinoflagellate bloom	Carancahua Bay	Matagorda	2456	<100
Fish kill	11 Jun 1992	Crop dusting and recent rainfall event	Carancahua Bay	Calhoun	2456	20
Fish kill	11 Jun 1992	Heavy runoff from concentrated rainfall	Carancahua Bay	Calhoun/ Jackson	2456	No Count
Fish kill	30 May 1996	Catfish virus	Lavaca Bay Palacios Creek to Garcitas Cove	Jackson	2453,1501, 2452	3500
Fish kill	04 Jul 2001	Rainfall upstream caused a phytoplankton bloom and low DO	Carancahua Bay upstream to Carancahua Creek	Jackson	2456	10,005
Fish kill	27 Dec 2003	Seismic	Carancahua Bay	Calhoun	2456	30,216
Fish kill	18 May 2004	Seismic	Matagorda, Lavaca, Chocolate, Cox, Keller & Carancahua Bay	Calhoun	2456,2455 2454,2453 2451	28,289

METHODOLOGIES

Site Selection Criteria

Three fixed sampling stations were selected in each stream; one station characteristic of the upper tidal reach, one characteristic of the middle, and one characteristic of the lower tidal reach. Stations were selected from stations existing in the Surface Water Quality Monitoring (SWQM) portion of the TRACS database, or Station Location Requests were submitted for sample collection stations not already existing.

The mid-coast sampling sites were selected from a landscape perspective. TPWD personnel trained in landscape ecology, estuarine ecology and estuarine biology visited each of the three streams. Sample sites were selected according to vegetation types present. The lower tidal reach stations (Station 3) had *Spartina alterniflora* present and the landscape was noticeably flattened out. At the middle station, the vegetation was dominated by species that were far more brackish-water tolerant for example *Spartina patens* and *Scirpus americana*. In the upper station, vegetation, like oak and elm trees, more tolerant of freshwater were present. At Station 1 the banks of the creek were steeper and much deeper than at the middle or lower stations. Locations of sampling sites on Tres Palacios, Garcitas Creek, and West Carancahua are shown in Figures 6 - 8. Table 13 has a physical description and location of each station.

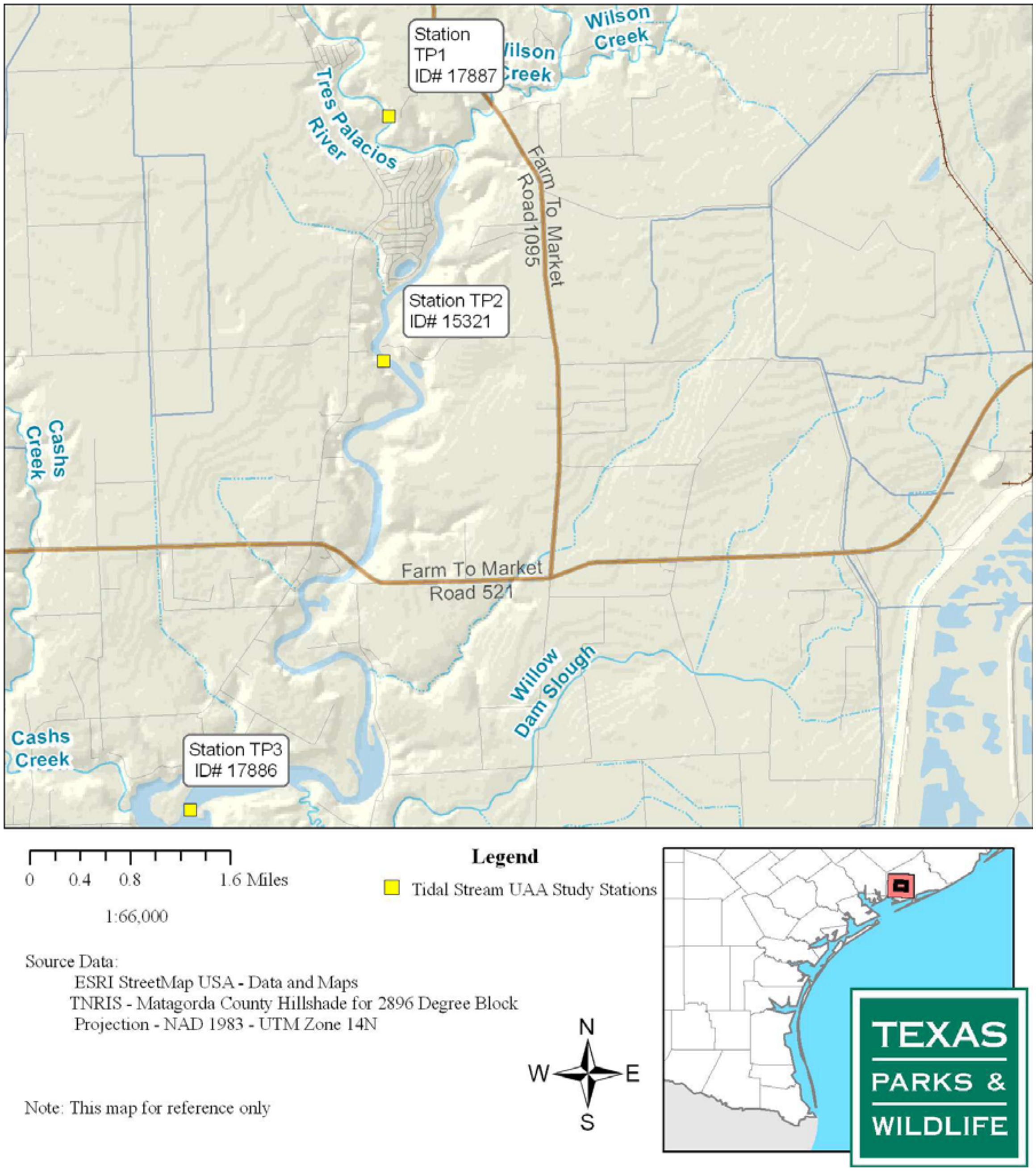


Figure 6. Fixed sampling locations on Tres Palacios River Tidal.

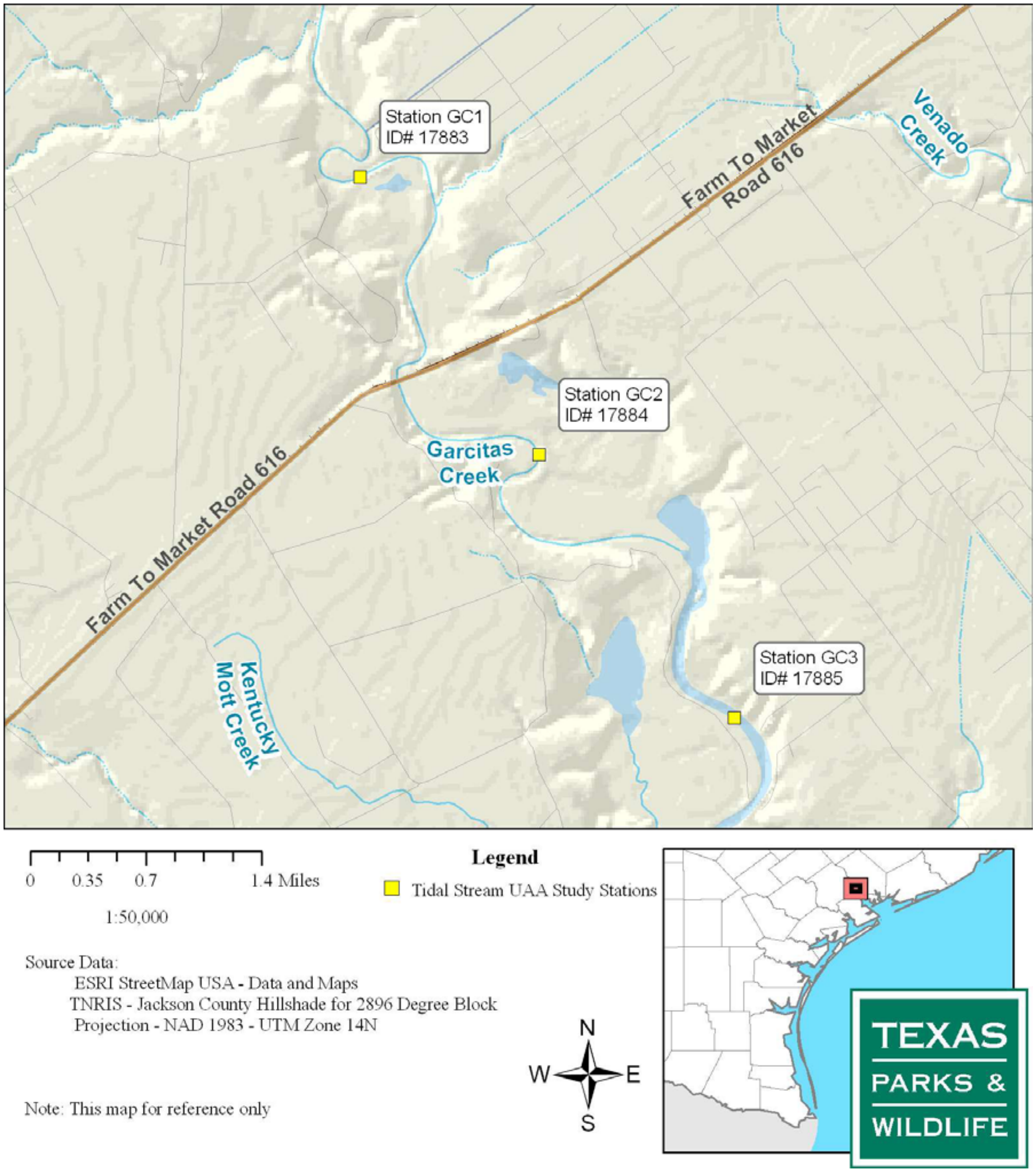


Figure 7. Fixed sampling locations on Garcitas Creek Tidal.

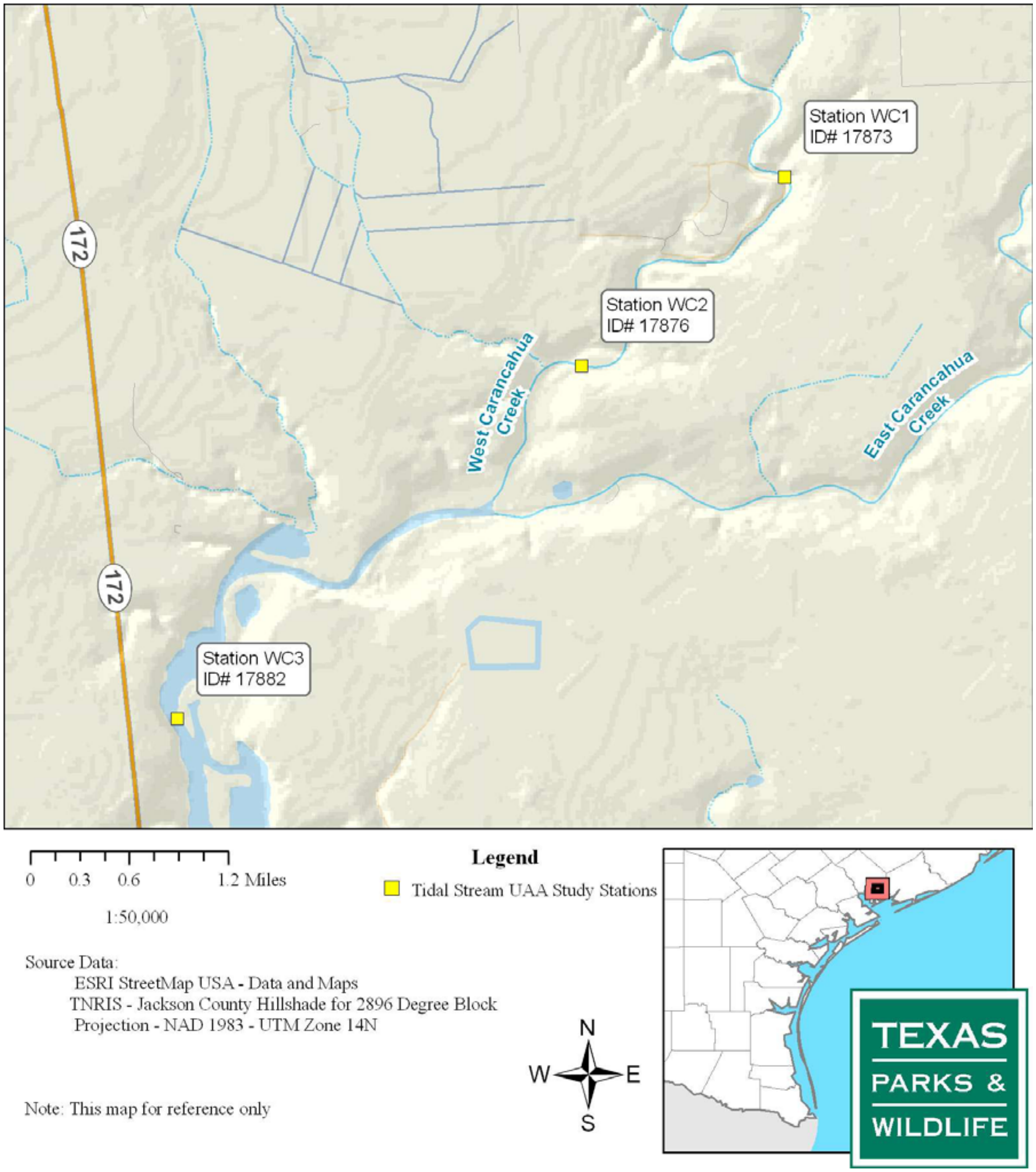


Figure 8. Fixed sampling locations on West Carancahua Tidal.

Station Descriptions

Physical descriptions for fixed sampling location are given in Table 13. Table 14 demonstrates the cross-sectional area of each station.

Table 13. Monitoring sites on the mid-coast tidal streams.

TCEQ Region	TCEQ SWQM Station ID	TPWD UAA Station ID	Site Description
12	17887	TP1	Tres Palacios River Tidal approximately 1.5 km upstream of the confluence of Wilson's Creek
12	15321	TP2	Tres Palacios River Tidal 3.75 km upstream of State Highway 521, Northeast of Palacios
12	17886	TP3	Tres Palacios River Tidal approximately 7.5 km downstream from State Highway 521
14	17883	GC1	Garcitas Creek Tidal approximately 3.1 km upstream of FM 616
14	17884	GC2	Garcitas Creek Tidal approximately 1.80 km downstream of FM 616
14	17885	GC3	Garcitas Creek Tidal approx. 6.5 km downstream of FM 616
14	17873	WC 1	West Carancahua Creek Tidal approximately 5.1 km upstream of confluence with East Carancahua Creek
14	17876	WC 2	West Carancahua Creek Tidal approximately 1.9 km upstream of confluence with East Carancahua Creek
14	17882	WC 3	West Carancahua Creek Tidal approximately 4.5 km downstream of confluence with East Carancahua Creek

Table 14. Mean cross-sectional area (ft^2) ± SD of all stations on study streams. Mean area was determined based on measurements recorded by the SonTek ADCP. Estimates do not include areas associated with the surface and bottom blanking distances or shallow edges.

Stream Station	West Carancahua	Garcitas Creek	Tres Palacios River
1	712 ± 77	816 ± 289	833 ± 119
2	739 ± 80	1,256 ± 347	1,168 ± 153
3	1,391 ± 296	1,785 ± 349	1,203 ± 267

Sampling Methods

Sampling for physiochemical, water chemistry, flow, nekton and aquatic invertebrates was conducted in Tres Palacios River Tidal, Garcitas Creek Tidal, and West Carancahua Creek Tidal, six times annually for two consecutive years. Replicate seasonal sampling took place twice each in the spring, summer, and fall of 2003. The entire sampling protocol was repeated in 2004, resulting in a total of 12 sampling trips.

Sediment composition and benthic infaunal communities were sampled once each season. Sampling occurred once in the spring, summer, and fall seasons during 2003, and the entire protocol was repeated again in 2004. Sediment and benthic infaunal community sampling resulted in six total collection trips.

With few exceptions, biological, flow and physiochemical data were collected concurrently at the same stations within the same calendar week. Stream characteristics dictated minor modifications of the sampling methods for each site. The riparian corridor and instream habitat were characterized once for each station in the spring of 2003.

Documentation of Field Sampling Activities

Field sampling activities were documented on field data sheets. Flow work sheets and multi-probe calibration records were part of the field data record. For all visits, station ID, sampling time, date, depth, and sample collectors' names were recorded. Detailed observational data were recorded including water appearance, weather, biological activity, stream uses, unusual odors, specific sample information, missing parameters (items that were to have been sampled that day, but weren't), days since last significant rainfall, and flow severity.

Recording Data

All field and laboratory personnel followed the basic rules for recording information as documented below:

1. Legible writing in indelible, waterproof ink with no modifications, write-overs or cross-outs,
2. Correction of errors with a single line followed by an initial and date;
3. Close-outs on incomplete pages with an initialed and dated diagonal line.

Landcover Classification

Landcover was analyzed for all three streams. The contributing basin of each stream segment was delineated. This was done from either USGS Hydrologic Unit data where available or from the National Elevation Dataset digital elevation model using algorithms developed by Environmental System Research Institute, Inc. (ESRI). Analysis including but not limited to determining the amounts of different landcover types contributing runoff to the streams, amounts of impervious cover in the watershed, and human population density in the watershed was conducted.

Landcover Classification Procedures

Landcover was developed using ERDAS, Inc. Imagine Image Processing Software. Each watershed was mapped separately using “cluster busting” unsupervised classification algorithms. LandSat 7 ETM+ data acquired by the State of Texas was used to map the landcover. The LandSat data was subset to each watershed and an initial unsupervised classification was performed. The results of this algorithm were consolidated into 4 classes: water and marsh, exposed/lightly vegetated, woody, and herbaceous. Each class was then used to subset the original LandSat data and another unsupervised classification was run, resulting in 50 clusters. These pixel groups were then assigned, by an analyst, to a particular landcover class. Landcover classes were based upon the Nature Conservancy’s Terrestrial Vegetation of the Southeastern United States (Weakley et al., 1998). Additional classes for exposed lands and urban/industrial classes were added to the schema. Once all the clusters were assigned to a landcover class, for all four subsets of the data, they were reintegrated into one dataset. The landcover data was clumped so that the minimum mapping unit is at least one (1) acre, using the CLUMP and ELIMINATE routines in Imagine.

The landcover was verified using data collected in the field with a global positioning system device for positional accuracy. Data were collected by randomly selecting a driving route and stopping every 0.5 mile to collect points. At least 10 points per landcover class were collected. Data recorded for each point included landcover class, 3 visually dominant plant species, if applicable, and a direction and offset from the road. Minimum offset was at least 40 meters. Accuracy was at least 85% in all core landcover classes. Core landcover classes were grassland, shrub-land, marsh, open water, upland forest, bottomland forest, mesic forest, agricultural lands, and urban/industrial. Data was re-analyzed and ancillary datasets used to increase accuracy until the above condition was satisfied. The accuracy assessment process was then repeated. This iterative process was repeated until the minimum accuracy for each core landcover class was satisfied.

All Watershed Analysis

The watershed for each stream was delineated from remotely sensed imagery, USGS 8 digit Hydrographic Units and field data. The land cover map was clipped to the boundary of the watershed and the total area in each land cover class was calculated. The percent cover for each land cover class was calculated. The difference between the reference stream and each study stream was then calculated.

Stream Buffer Analysis

The center of channel was delineated from remotely sensed imagery for each stream, this included secondary and in some cases major tertiary contributory streams. A 200 meter buffer was then created using the stream centerlines. This buffer was used to clip the land cover map. The total area for each land cover class within the buffer area was then calculated. The percent cover for each land cover class was calculated. The difference between the reference stream and each study stream was then calculated.

Urban Index Analysis

Tiger Roads files were clipped to the study area boundaries. The roads were then converted from vector to raster format (15m cell). Rasterized roads were then reclassified to binary (where road = 1, other = no data). The rasterized binary roads were then merged with the Urban Class from the landcover classification. Raster masks from study area boundaries were created. The merged Roads/Urban Class files were then masked to the study area boundaries.

A neighborhood analysis was then conducted on the masked Roads/Urban Class files where:

Field = value; Statistic = Sum; Neighborhood = rectangle; Height = 450m; Width = 450m; Output cell = 30m

Output files from the neighborhood analysis were reclassified using a five class natural breaks classification. For Carancahua Creek, Garcitas Creek and Tres Palacios River the lowest two classes were thrown out and the remaining 3 classes were reclassified as low, medium, and high.

Instream and Riparian Habitat Classification

Habitat data were collected in the spring (April and May) of 2003. Habitat characteristics were surveyed according to methods outlined in the U. S. Environmental Protection Agency's Environmental Monitoring and Assessment Program (EMAP) document entitled, "Field Operations and Methods Manual for Non-Wadeable Streams" (Lazorchak et al. 2000) except where noted. Habitat classification was conducted a single time for each stream (Tres Palacios River Tidal, Garcitas Creek Tidal and West Carancahua Creek) at 3 sampling reaches per stream. Each sampling reach was subsampled at 11 transects (Lazorchak et al. 2000), and the transect locations were recorded using a global positioning system. For a more detailed description of the methodology used to sample each of the following variables refer to Lazorchak et al. (2000). Variables measured included: 1) a thalweg (i.e., maximum depth) profile along the length of each stream sampling reach that included an estimate of bottom substrate type and channel habitat type; 2) an estimate of littoral (i.e., channel bank) depth and substrate type along the margin of the channel at each transect location; 3) an estimate of the coverage of large woody debris in each channel reach; 4) a measurement of channel physical characteristics which included channel wetted width, presence of bars or islands and their width if present, bankfull width, bankfull height, channel incised height, and bank angle/degree of bank undercutting; 5) an estimate of canopy cover along channel banks using a densiometer; 6) another measure of riparian vegetative structure involving separate visual estimates of canopy, understory and groundcover vegetation; 7) an estimate of fish cover and aquatic vegetation within the channel; and 8) an estimate of the degree of human influence in the immediate sampling area around transects. The portion of the EMAP methodology pertaining to "legacy trees" was not included in this study as well as the section on invasive/alien plant species. Channel sinuosity was also estimated using geographical information system analysis. The length of each stream reach was found along the channel of stream "as the fish swims". Then the straight line distance from start of reach to end of reach was found "as the crow flies". Then the channel length was divided by the straight length. The larger the number was the more sinuous the stream (Kaufmann et al 1999). Densiometer measurements were taken following the manufacturer's instructions rather than the method suggested by Lazorchak et al. (2000). Measurements of channel margin depth and substrate type were estimated using a polyvinyl chloride (PVC) pole along banks where the water was too deep to reach the bottom. Because coastal streams have a very low gradient, channel slope as discussed in Lazorchak et al. (2000) was not measured. The presence of power lines was also added to the portion of the method measuring human influence.

Instream Flow Characterization

Texas Water Development Board (TWDB) staff assisted in initial site selection collected supporting hydrographic data, and analyzed flow data. Data extracted included tidal and residual components of flow, as well as summary discharge and velocity data. Detailed information can be found in Appendix 4**.**

TPWD staff measured flows at each stream station with a 3 MHz SonTek River Surveyor. The SonTek River Surveyor is a boat-mounted acoustic Doppler profiler that was used to record instantaneous measurements of velocity and discharge in the stream channel. Flow was measured in each of four transects perpendicular to the channel length at the same point near the sampling station. Typically two transects measured flow while the boat moved from right bank to left bank and two transects measured flow while the boat moved from left bank to right bank. The time to measure flow in the four transects varied between sites and sampling dates but ranged from 25 to 40 minutes at each site.

Sampling was designed to facilitate making flow measurements concurrently with water chemistry sampling. Weather conditions, equipment and personnel limitations, as well as mechanical problems made it difficult to measure flow each time water chemistry was sampled.

A SonTek Argonaut XR acoustic Doppler current meter was deployed at the middle station in each of the three streams for at least 24 hours (in order to record flow over an entire tidal cycle) during each sampling trip. The Argonaut XR was deployed on the bottom of the stream within 7 m of the shore. This instrument averaged and recorded measurements in water velocity, direction and water height over 5-minute intervals. The bottom-mounted, up-looking SonTek Argonaut XR acoustic Doppler velocimeter (ADV) was used to measure stream flow direction and velocities over periods of time to include at least one complete tidal cycle.

Argonauts were not used until the third trip (June 2003). Boat-mounted ADCP current profilers (down-looking) were used from the beginning of the study.

Water Quality

Physiochemical Profiles

Field physiochemical data profiles were measured using instantaneous water quality reading instruments calibrated to the manufacturers' specifications. Data were recorded approximately 0.3 m below the surface, 0.3 m above the bottom, and instream stations of sufficient depth, halfway between the surface and the bottom readings. Secchi depth was also recorded. On rare occasions, profiles were not collected due primarily to flooding conditions. At Tres Palacios Station 3, measurements were only taken at the surface during the study, because the depth at this station was consistently very shallow (<1m).

Short-Term 24-hour Deployments

Multiparameter logging sondes were deployed at each sampling station on each study stream. Temperature, dissolved oxygen, salinity, and pH were logged every half-hour for 24 hours. The sondes were deployed with the sensors approximately 0.3 m below the water surface. Calibration records were retained for each deployment. One of the main problems encountered with deployments was an insufficient number of fully functional datasondes. In 2003, many datasondes were not equipped with pH probes, so pH data were not collected. Calibration problems were another leading problem encountered. Fluctuations in water levels after datasondes were deployed, flooding and equipment malfunctions were other challenges encountered.

Long-Term Physiochemical Measurements

Stevens Greenspan CS304 multi-parameter datasondes were deployed on every study stream. The Greenspan datasondes were used to collect a much longer time series of water temperature, dissolved oxygen, pH, and specific conductance. To capture differences between surface and bottom water quality, two datasondes were deployed per site; one near the surface and the other near the bottom. Datasondes were routinely left in place for durations of approximately six weeks per deployment. When only one datasonde was available per station, a single instrument was deployed at the surface.

The datasonde deployment sites were generally in the middle of the study reach. Greenspan deployment sites include Tres Palacios Station 2, Garcitas Creek Station 2 and West Carancahua Creek Station 2.

The datasondes were deployed using an anchor, chain, and buoy system. The chain connected the anchor to the buoy and the datasondes were suspended from the chain. Chain length was greater than the water depth to help keep the instrument near the surface during flooding events and high tide. Because there was slack in the chain, an additional buoy was attached above the bottom datasonde to keep it from lying on the sediment. To keep the bottom datasonde out of the sediment it was deployed upside down, with the sensors pointing towards to surface. The datasondes are approximately one meter in length. To keep the sensors near the surface, the surface datasonde was also deployed upside down.

The Greenspan datasondes were calibrated before each deployment and post calibrated after retrieval. In many cases the dissolved oxygen diffusing rods leaked, causing the sensor to fail. The specific conductance sensor had a large range (0-50,000 µS/cm), although at very low conductivities (<1000 µS/cm), the probes were not reliable.

Water and Sediment Samples

Water and sediment samples were collected for laboratory analysis of the parameters presented in Table 15.

Field Sampling Procedures

Sampling procedures for field and conventional chemical parameters documented in the TCEQ Surface Water Quality Monitoring Procedures Manual (1999a) were followed unless otherwise noted. Specifically, field sampling procedures followed Chapter 4, "Water Sample Collection," pages 4-1 through 4-2. Additional procedures for field sampling outlined in this section reflect specific requirements for sampling under this TMDL Project and/or provide additional clarification. In addition a water sample was collected approximately one foot above the bottom. Chlorophyll a and pheophytin analyses were not conducted for bottom samples. Procedures outlined in the SWQM Manual, Chapter 5 ("Sediment Sample Collection") were followed for collecting the sediment samples.

More detailed documentation on sample handling and custody, analytical methods, instrument/equipment testing and inspecting, maintenance, and quality control measures used for the water and sediment samples collected for this project can be found in TPWD (2004).

Biological Sampling

Nekton Collections

Nekton collections on the mid coast streams were made by seines, gill nets, and otter trawls. Sampling protocols for each gear followed the established procedures found in the "Marine Resources Monitoring Operations Manual" (TPWD 2001), with some minor gear modification to allow for the small spatial areas of tidal streams under investigation.

All nekton collected were identified in the field, enumerated, and measured to the nearest millimeter. Nekton that could not be identified in the field were preserved on ice or in formalin and transported to the lab for identification. Voucher specimens of each species were retained in 10% formalin to allow secondary verification of identifications. Voucher specimens too large to fit in a five-gallon bucket were photographed for verification of identification. Vouchers are currently stored at TPWD facilities in Corpus Christi, Tyler and San Marcos until a final review of the UAA reports for each tidal stream. After completion of each report, all vouchers will be archived in the Natural History Collection of the Texas Memorial Museum in Austin, Texas.

Catch per unit effort (CPUE) for seining was recorded as the total number of individuals per linear foot seined at each site; CPUE for electrofishing was.

Table 15. Field sampling and handling procedures for water and sediment samples.

Parameter	Matrix	Container	Preservation	Sample Volume	Holding Time
TSS/VSS	Water	Pre-cleaned glass or cubitainer	4º C, dark	400 mL	7 days
TDS	Water	Pre-cleaned glass or cubitainer	4º C, dark	250 mL	7 days
Chloride	Water	Pre-cleaned glass or cubitainer	4º C, dark	100 mL	28 days
Sulfate	Water	Pre-cleaned glass or cubitainer	4º C, dark	100 mL	28 days
Total Phosphorus	Water	Pre-cleaned glass or cubitainer	4º C, dark, pH<2 with H_2SO_4	150 mL	28 days
Total Kjeldahl Nitrogen	Water	Pre-cleaned glass or cubitainer	4º C, dark, pH<2 with H_2SO_4	200 mL	28 days
Nitrite+Nitrate Nitrogen	Water	Pre-cleaned glass or cubitainer	4º C, dark	150 mL	48 hours
Ammonia-Nitrogen	Water	Pre-cleaned glass or cubitainer	4º C, dark, pH<2 with H_2SO_4	150 mL	28 days
Ortho-Phosphorus	Water	Pre-cleaned glass or cubitainer	4º C, dark	150 mL	28 days
Total Organic Carbon	Water	Pre-combusted borosilicate glass bottle	4º C, dark, pH<2 with H_2SO_4	100 mL	28 days
Chlorophyll-a	Water	Cubitainer	4º C, dark	1000 mL	filter < 48 hrs; filter may be stored 30 days
Pheophytin-a	Water	Cubitainer	4º C, dark	1000 mL	filter < 48 hrs; filter may be stored 30 days
$CBOD_5$	Water	Plastic or glass	4º C	4000 ml	48 hours
Grain Size	Sediment	Glass	4º C	500 g	14 days
Percent Solids	Sediment	Glass	4º C	500 g	14 days

recorded as the total number of individuals captured per unit time; and CPUE for gill netting was recorded as total number of individuals per hour net set. CPUE for trawling was the total number of individuals collected per hour of trawling.

Seines

The 30-foot seine was 8 feet deep using a 3/16 inch delta material with double floats and double lead weights. An effective seine haul was one that was not affected by hang-ups or lifting the net off the bottom. Because of a narrow shelf and a steep channel profile on the side of many of the sampling stations, many areas were too deep to wade the deep end of the seine. In that case, one end of the seine was walked or held against the bank and the seine was deployed perpendicular to the shore with the boat then maneuvered back in an arc to shore with the boat. At each sampling location, seine pulls were repeated until a linear distance of 125 feet of shoreline had been covered.

Rarely seine data were not collected due to nets torn by underwater woody debris. Changing water levels within the tidal streams added another level of variability to the seine results. For example, during high water conditions, it was necessary to seine on what were normally the upper banks of the stream, and target organisms potentially could escape into the adjacent flooded vegetation. Conversely, when water levels were very low, the wadeable shelf along the shore was very narrow and there was little vegetated area to sample.

Trawls

For trawl collections, a 10-ft otter trawl was used. Trawling was conducted for three five-minute intervals (not covering the same area) at constant engine speed of 1300 revolutions per minute (RPM) or approximately 3 mph. There were problems with snagging woody debris throughout the study. Flooding conditions frequently created new woody debris snags at stations. If the trawl duration lasted at least three minutes before becoming entangled, it was considered an adequate effort. If trawl sampling duration was less than three minutes and it became snagged, the contents of the trawl were released, no data were recorded, and the trawl was repeated. In rare situations, trawls were snagged repeatedly at a station, and the effort was ended with no data recorded for that station. In April 2003 a strong cold front lowered the water level to the extent that Tres Palacios Station 3 could not be trawled.

Gill Nets

Monofilament gill nets were a total of 100 feet in length with 25-ft intervals of mesh size 1, 2, 3, and 4-inch bar measurement. Gill nets were 8 feet deep with a float core and 30 pound lead core. Gill net sets were located at each sampling station perpendicular to the stream bank, or diagonal to the bank if the width of the stream did not permit a perpendicular set. In each gill net set, the smallest mesh was located nearest the shore. Gill nets were set within one hour of sunset and retrieval began within one hour of sunrise.

Gill net samples were frequently compromised by alligator depredation and flooding conditions. Alligators taking fish from the gill nets and getting trapped in the nets often created large holes in the nets. No information about the fish the alligators consumed or destroyed could be recorded. Flood conditions also compromised gill nets collections. Large amounts of debris collected in the nets forced the nets out of position and/or reduced the area of net effective for capturing fish.

Electrofishing

Conductivity at the mid-coast sampling stations frequently exceeded the recommended range identified by the manufacturer, therefore it was decided that the electrofishing equipment would not be an effective gear for sampling nektonic organisms from the mid-coast locations.

Sediment and Benthic Macroinvertebrate/Infaunal Collections

At each station, benthic organisms were collected from one randomly chosen side of the stream and from the mid-channel area. Five replicate samples were collected from both the side and middle locations, resulting in a total of 10 replicates per station. Each replicate was individually labeled and processed separately. Whole collections were first placed in a 500-micron mesh bag, field-washed to remove the majority of the sediment, and preserved in 10% buffered formalin with Rose Bengal. Benthic infaunal community samples were delivered to the Center for Coastal Studies at Texas A & M University Corpus Christi (TAMU-CC) for identification and enumeration. On trips when benthic infaunal data were collected, one additional sediment sample was also collected and analyzed separately for grain size, total organic carbon, and percent solids. Sediment samples were collected with the same gear as the benthic infaunal communities.

On the middle coast, the benthic suction corer, constructed after Onuf et al. (1996) with minor modifications, was used to collect both the sediment and benthic invertebrates. The corer was 10.2 cm in diameter (area = 81 cm^2) and was designed to be inserted 10 cm into the sediment. Approximate sample volume = 810 cm^3. A correctly collected benthic core appeared to fill the coring portion of the device after the vacuum is released, with approximate size of the core = 10 cm in length. When the core was released from the device, care was taken so that sediments clinging to the outside of the device were not included in the sample. When the substrate was too hard or too sandy to be collected by the suction coring device, a Petite Ponar grab sampler was employed. The Petite Ponar measured 6 inches long by 6 inches wide by 6 inches deep, yielding an approximate sample volume of 216 cubic inches. If the sample was retrieved with the jaws of the Ponar not completely closed or the sampler was not completely full, the sample was discarded and the grab was repeated.

Aquatic Invertebrate Collections

Aquatic invertebrates in shoreline habitats were sampled with a D-frame net. Five minute sweeps of all the available cover and instream habitats (e.g., near surface, near bottom, floating debris, submerged aquatic vegetation, overhanging vegetation, etc.) were conducted on each side of the stream at each station. Samples were preserved in the field in the same manner as the benthic samples, and delivered to the Center for Coastal Studies at TAMU-CC for identification and enumeration.

The laboratory evaluations of the aquatic invertebrates are based on methods described in the Center for Coastal Studies publication, "Benthic Macroinvertebrate Methods," (Withers and Tunnel 1999). Samples were first sorted into major taxonomic groups, then further identified to lower taxonomic levels and enumerated. Samples from 2003 were identified to species level when possible but due to time constraints during 2004 identification was only to the Family level. Results will show that this had no appreciable effect. A senior taxonomist oversaw and periodically reviewed the work performed by technicians. Identification and enumeration of the benthic invertebrate and aquatic insect samples were done by experienced graduate research assistants under the supervision of senior research scientists. An established regime of in-house QC checks was adhered to, in which a portion of each technician's work was reviewed by a senior taxonomist; a failed check required that all of that technician's samples, since the last passed check, be re-sorted or re-identified (depending on the assigned task). The same type of QC checks applied throughout the process of identifying and quantifying the benthos and insects; technicians and taxonomists had their work verified by a peer or more senior taxonomist. The QC checks were well documented in a laboratory notebook that is available to Tidal Streams UAA project quality assurance staff on request.

Occasionally sediment or benthic macroinvertebrate samples were not collected due to flooding conditions, weather, or equipment malfunctions. D-frame net sweeps for aquatic invertebrates were not conducted in only a few instances due to high water levels or inclement weather.

Quality Control

Sampling done as part of this study followed quality control (QC) requirements as outlined in the TCEQ Surface Water Quality Monitoring Procedures Manual. See the Quality Assurance Project Plan (TPWD 2004) for details of field and laboratory quality assurance and quality control procedures.

For the water chemistry samples, for the first three trips field duplicates were collected. Beginning with the fourth trip in August 2003, field splits were collected. One QC sample was obtained for every ten water chemistry samples or portion thereof. Precision of duplicate and split results was analyzed. If precision for a parameter was outside of the acceptable range then results for that parameter were flagged for further investigation. Individual sample results were examined for discrepancies to determine if the data should be discarded. No results were discarded based on comparison of duplicates and splits.

Equipment blanks were collected once per trip for each type of equipment (bucket, Niskin bottle, etc.) that was used to collect a water sample. No equipment contamination was observed during the study.

Data were generally reliable. Sample results for 2003 sampling trips were accompanied by comments from the laboratory. Where such comments indicated a potential problem, individual results were examined. Following discussion with TCEQ staff, most results were deemed acceptable. Only about 55 of about 484 sample results taken in 2003 were discarded. In 2004, the laboratory changed their procedures and simply did not report data that they believed to be unreliable, so no additional analysis was required. In both 2003 and 2004, samples were discarded that arrived at the laboratory in leaking containers, outside of the acceptable temperature range, or for which holding times were exceeded. Additional computerized data checks were done to ensure data quality prior to submitting data to TCEQ.

Prior to deployment, multiparameter datasondes were calibrated according to manufacturers' instructions. Diurnal water quality measurements were logged electronically and later downloaded to computers. Instruments were post-calibrated and post-calibration records were checked for each deployment to verify that instruments did not exceed the criteria required by TCEQ (page 9-11 of the TCEQ Surface Water Quality Monitoring Procedures). Data for a given parameter were discarded when post-calibration did not meet acceptable limits for that parameter. Other QA/QC activities included verifying that data were reported in the correct units.

The goal of each deployment was to collect a complete 24-hour set of measurements, which were averaged to determine means, maxima and minima for the various parameters. In some cases the datasondes were deployed for less time than 24 hours. In those cases, mean values and other statistics were calculated from several measurements, evenly spaced throughout the deployment period (e.g. every three hours) and intervening measurements were discarded and not included in the analysis.

Original field data sheets are maintained in the TPWD Austin office under the supervision of the Project Manager. Copies of the data sheets were provided to the Data Manager, QA Officer and data entry personnel. Laboratory data were provided electronically to the Data Manager and in hard copy to the QA Officer. A Microsoft Access database was created to manage the data. Field data were entered manually and laboratory and datasonde data were uploaded. Electronic files are stored on the TPWD network. All data is backed up on network drives and on compact disk.

Quality checks were made on all data that was keyed into electronic format. Internal checks were run to ensure consistency between TCEQ laboratory data labeling and TPWD sample identification and to verify that data could be retrieved and that units were appropriate.

Hard copies of all field data, QA/QC checklists and quarterly reports are kept on file at the TPWD office (Coastal Fisheries Division) at 3000 South IH-35, Suite 320, Austin, Texas 78704. All documents will be kept for 5 years as stipulated by the TCEQ.

Analysis Techniques

The major purpose of this study was to collect the information necessary to develop a biological assessment method that can be applied to tidally influenced streams. Assessment methods which have been utilized for inland surface waters as well as estuarine and coastal marine waters have historically been based on establishing biological criteria which measure the ecological health and diversity of the biological communities characteristic of these water bodies. These biological criteria can serve as guidelines or benchmarks adopted by regulatory agencies to evaluate the biological integrity of surface waters. The concept of biological criteria can serve as a practical approach to establishing management goals designed to protect or restore biological integrity (Gibson et al. 2000). The criteria themselves are defined as “narrative expressions or numerical values that describe the biological integrity of aquatic communities inhabiting waters of a given designated aquatic life use” (USEPA 1990). Coupled with the traditional physical and chemical criteria used by the EPA and TCEQ to establish the beneficial use classifications of surface waters, the integration of the biological assessment provides for a more holistic approach to the protection and management of aquatic ecosystems. Currently, no established methodology exists for assessing the biological integrity of tidally influenced streams in Texas.

Bioassessment, coupled with habitat assessment, helps to identify probable causes of impairment that may not be detected by the more traditional physical and chemical water quality analyses alone. The detection of water resource impairment, accomplished by comparing biological assessment results to the biological criteria, leads to more definitive chemical testing and focused investigations which should reveal the cause of the degradation (Gibson et al. 2000). This in turn should lead to an evaluation of the source of the impacts (either point source or non-point source) and a determination of the effectiveness of any control measures recommended for these sources (i.e., the application of the TMDL process).

A central principle of a biological assessment is the comparison of a water body to a biological criterion, based in part, on a reference condition (Gibson et al.

2000). Impairment of the water body under investigation can then be judged by its departure from the biocriteria. In this conceptual framework, comparative assessment is predicated on the ability to define, measure, and compare biological integrity between similar systems. Because absolutely pristine tidal river segments do not exist along the coast of Texas, comparisons must be made with the understanding that reference segments exist with some minimal level of acceptable impacts.

In their technical guidance document that establishes the protocols for establishing biocriteria, Gibson et al. (2000) recognize that reference conditions need to be established in a variety of ways. They should include information derived from various sources:

> **Historical Data** are usually available that describes biological conditions in the region over some period of time in the past. Careful review and evaluation of these data provide insight about the communities that once existed and/or that may be reestablished. Review of the literature and existing data is an important initial phase in the biocriteria development process. However, if data have not been collected for this specific purpose, they need to be carefully reviewed before being applied,
>
> **Reference Sites** are minimally impaired locations in the same or similar water bodies and habitat types at which data are collected for comparison with test sites. Reference sites could include sites that are away from point source or concentrated nonpoint loadings; sites occurring along impact gradients (nearfield/farfield); and regional reference sites that may be applied to a variety of test sites in a given area,
>
> **Expert Opinion/Consensus** A consensus of qualified experts is always needed for establishing the reference condition; and helping develop the biocriteria. This is especially the case in impaired locales where no candidate reference sites are acceptable and models are deemed unreliable. In these cases, expert consensus is a workable alternative used to establish reference "expectations". Under such circumstances, the reference condition may be defined using a consensus of expert opinion based on sound biological principles acceptable to the region of interest. The procedures for these determinations and decisions should be well documented for the record.

The determination of the reference condition should also be developed from a population of sites, and not from a single site. A review of Contreras (2003a, 2003b, and 2003c) reveals the relative paucity of historical biological data that exists for these tidally influenced water bodies. To that end, even less historical data was available for most of the potential reference water bodies initially investigated (See Reference Streams, this document). TPWD staff have therefore relied heavily on the "Expert Opinion/Consensus" procedures outlined in Gibson et al. (2000) in making determinations of reference conditions.

Because each tidal stream station under investigation was characterized with respect to its potential for saltwater intrusion (e.g., upper, middle, and lower stations), site-specific reference conditions were also chosen to represent the upper, middle, and lower reaches, and these were paired with the corresponding test sites for all comparative purposes.

Owing to a general lack of available historical data, coupled with the absence of any established protocol for determining biological integrity in tidally influenced coastal segments, the initial task before the project team is to determine whether any statistical differences can be found between the reference streams and the study streams. Separate comparisons of the mid-coast and upper-coast impacted vs. reference streams will involve either parametric or non-parametric tests. The null hypothesis in all tests will be whether water quality or any other attainment indicator (e.g., biocriteria) at the study sites is significantly different from the conditions at the reference sites. The following techniques (or any combination that is identified through the Expert Opinion/Consensus criteria) will be used in the development of a Tidal Stream Site-Specific Use and Criteria Methodology:

Parametric Statistics

Parametric statistics, such as Analysis of Variance (ANOVA; F-statistic) and the t-test (t-statistic) are suitable for datasets that exhibit a normal distribution. In order to conclude that there is no significant difference between the water quality conditions (or any other attainment criteria) at the study sites and the control sites, both the F-statistic and the t-statistic should exhibit probabilities exceeding the 0.05 probability cutoff for the 95 percent confidence interval. In cases where multiple study sites are compared to the control site, parametric procedures such as Dunnett's test for comparisons with a control, Fisher's Least Significant Difference (LSD) test, or Duncan's Multiple Range test can be used to test for differences among the means.

Because water quality, biological, and sediment samples are often characterized by small sample sizes (in the case of water quality and sediment collections) or highly skewed, non-normal distributions (in the case of the nekton, benthic infauna, and aquatic insect collections), it is likely that nonparametric tests may be more appropriate for these datasets. Parametric statistics may be more useful for comparisons of instream and riparian corridor habitat data, flow, and short-term and long-term physiochemical measurements.

Principal components is another parametric-based statistical test that could potentially be used to reduce the sheer numbers of variables (WQ parameters, habitat variables, physiochemical parameters, etc.) down to a manageable subset that explains the greatest amount of total variation. These reduced principal component scores could then be used as a dependent variable either in logistical or multiple regressions; or similarly as the dependent variables for a multivariate analysis of variance (MANOVA). In each case, this reduced set of variables would still be testing for differences in the impacted vs. reference streams. A limitation posed by the sampling design is the large number of variables relative to the limited number of “replicates” or observations. Ideally, a five-to-one dependent variable-to-independent variable ratio (i.e., dependent variables to observations) is optimal to satisfy the assumptions of many multivariate parametric procedures (Johnson and Wichern 1992).

Non-parametric Statistics

Historically, many of the derived parameters (metrics) used in developing specific biocriteria can be classified as non-parametric community measures or indices, drawn from dynamic assessments of the fish, invertebrate, macrophyte, and planktonic assemblages that make up a biological community (Karr et al. 1986; Engle et al. 1994; Deegan et al. 1997; Allen and Smith 2000). These dimensionless indices are used to summarize a series of diverse community measures into one or more quantitative variables. Indices are used to reveal much of the underlying information inherent in the vast amount of raw data a biological assessment generates. In this realm of data reduction, indices are much akin to the principal components and canonical correlations tests. Indices are most often used to describe measures of community composition such as species abundance, diversity, evenness, richness, and dominance, or conditions such as incidence of disease, malformation, and parasite load, or distribution of year classes and age structure (Table 16).

Table 16. Potential metrics for biological communities that could be considered for tidally influenced streams. Reprinted from Gibson et al. (2000); Table 11-1, and modified for this study.

	Richness	Composition	Tolerance	Trophic / Habitat
Macrophytes	► Not applicable	► Not applicable	► TSS ► Light attenuation ► Chlorophyll a ► DIN ► DIP	► % Cover ► Density of new shoots ► Biomass ► Stem Counts
Benthic Macroinvertebrates	► Dominant taxa ► Taxa Richness ► Shannon-Wiener Diversity Index ► Mean # of species ► Pielou's Evenness Index ► Average taxonomic diversity	► # amphipods per event ► Amphipod biomass ► Mean abundance of bivalves/site ► # of gastropods per event	► % Polychaetes ► Polychaete biomass ► % Oligochaetes ► Oligochaete biomass	► % or biomass epibenthic ► % or biomass deposit feeders ► % or biomass suspension feeders

	Richness	Composition	Tolerance	Trophic / Habitat
Fish	► Dominant taxa ► Taxa richness ► Average taxonomic diversity ► # of estuarine spawners ► # anadromous / catadromous spawners ► Total fish exclusive of *Brevoortia* sp.	► Total # of species ► # species in bottom trawl ► # species comprising 90% of individuals ► # of marine species ►# of freshwater species	► #, %, or biomass of *Brevoortia* sp. ► #, %, or biomass of *Anchoa* sp. ► #, %, or biomass of Poeciliidae ► % Incidence of disease, tumors, or anomalies	► Proportion of planktivores ► Proportion of benthic feeders ► Proportion of piscivores ► Sciaenidae composition

Increasing levels of environmental stress have historically been considered to decrease overall diversity, decrease species richness, and decrease evenness (or conversely increase the dominance of a few species) (Clarke and Warwick 2001). This oversimplified interpretation of the effects of "stress" may, however, not be observed. Recent theories on the influence of disturbance or stress on diversity have suggested that in situations where disturbance is minimal, species diversity can be reduced due to competitive exclusion (Paine 1966; Connell 1978; Huston 1979; Dial and Roughgarden 1998; Payton et al. 2002). These works show that at slightly increased levels or frequencies of disturbance, competition is relaxed and an overall increase in diversity results. At even higher or more frequent levels of disturbance, species start to become eliminated by stress, so that overall diversity falls off. Thus it is at some intermediate level of disturbance that diversity is highest.

Depending on the starting point of the community under investigation, in relation to any existing stress levels, increasing levels of stress (e.g., induced by pollution), may either result in an increase or a decrease in diversity (Clarke and Warwick 2001). It is therefore difficult, if not impossible, to determine where a particular tidal stream community under investigation may fall along this continuum, or what value of diversity (or any other metric utilized to describe a specific biocriterion) would be expected if the community were not subjected to any anthropogenic stresses. Therefore, changes in diversity can only be assessed by comparisons between stations along a spatial contamination gradient or with historical data (Clarke and Warwick 2001). This conceptual framework was central to the site selection criteria outlined in this document. With a general lack of historic data on which to base any meaningful comparisons, it first must be established that significant differences can be detected within each study stream, and secondarily, that these differences deviate significantly from the expectations of the reference condition.

Multivariate ordination techniques form much of the basis of the biocriteria methodology proposed for tidally influenced streams. The PRIMER v6.0 (Plymouth Routines in Multivariate Ecological Research) software program will be used for all community-based analysis. Multidimensional scaling (MDS), or non-metric ordination of the samples, is a technique that constructs a "map" or a configuration of the samples in a specified number of dimensions that graphically represents the underlying sample patterns. The basis of the MDS is the similarity matrix among all the samples. These can include the biological data, the physiochemical data, or any of the datasets collected for this study. Separate ordinations of the stations can then be related by the rank correlations of the different similarity matrices. MDS is computationally more efficient than parametric-based techniques, and there is no need to limit the "dependent variable" side of the equation to the most abundant species (as is the case of an ANOVA or MANOVA of the biological data).

Similarities between each pair of samples are calculated using the Bray-Curtis similarity measure (for biological data) or Euclidean Distance (for the environmental and physiochemical data). The Bray-Curtis measure is defined as:

$$S_{jk}(i) = 100 \left\{ 1 - \frac{\Sigma_{i=1}^{p} \left| y_{ij} - y_{ik} \right|}{\Sigma_{i=1}^{p} (y_{ij} + y_{ik})} \right\} \qquad \text{Equation 1}$$

where y_{ij} is density of the i^{th} species in the j^{th} sample, and y_{ik} is the density of the i^{th} species in the k^{th} sample. In the Bray-Curtis measure, S = 0 if the two stations have no species in common, and S = 1 if the community composition is identical, because $| y_{ij} – y_{ik} |$ = 0 for all i.

Different transformations of the raw data can place additional weight on the rarer species, allowing for a more complete picture of the biological community to emerge. Agreement between the configurations of the different datasets can be measured by weighted Spearman's rank correlation. This allows for the species configuration (the biological picture) to be confirmed or rejected by the configurations of the "other data" (the physical and chemical pictures) that was collected concurrently. Stated another way, this technique reveals if the patterns in the biology agree with the patterns seen in the physical and chemical constituents reflective of each water body.

Second stage MDS (Clarke and Warwick 2001) is a time-series technique incorporating the Spearman Rank correlations between the underlying similarity matrices calculated for each sample date-Station two-way layout. Second stage MDS concentrates only on whether the community pattern among the stations is similar temporally across sample dates. Second stage MDS will be instrumental in documenting variability over seasons and as well as across years.

Analysis of Similarity (ANOSIM) is analogous to the parametric-based ANOVA in that it requires the same *a priori* designations of impacted or reference streams, but it is not nearly as limited as an ANOVA because there are no parametric assumptions placed on the data. The multivariate form of the similarity matrix, which is the same foundation of the MDS procedure, is the basis for this test. This test is built on a simple non-parametric permutation procedure, applied to the (rank) similarity matrix underlying the ordination of the samples. The procedure constructs a test statistic (R) based on the ranks of the similarities within and between stations. This value is then tested for significant differences against a null distribution constructed from random sampling of all possible permutations of the sample labels (Clarke and Warwick 2001). Values of the R-statistic close to unity show that the community compositions of the samples are very different, whereas those close to zero demonstrate that they are very similar.

The SIMPER (SIMilarity PERcentages – PRIMER v5.0) routine will be used to examine the contribution of individual species (i) to the community structure seen at each station (see Equation 1). Values of $S_{jk}(i)$ are averaged over all pairs of samples (j,k) between stations to give the average contribution. The ratio of $Savg_{(i)}$ to its standard deviation indicates how consistently a species discriminates among the assemblages. If a species is found at consistent levels (i.e., densities) across all samples at a station, then the standard deviation of its contribution is low, and the ratio is high (Clarke and Warwick 2001). Such a species will contribute more to the intra-group similarity, and can be thought of as typifying that group. Candidate species for “indicator taxa” (those that are either tolerant or intolerant to pollution/water quality degradation/low dissolved oxygen, nutrient loadings, etc.) can be identified with this test.

Average taxonomic diversity and distinctness tests address some of the shortcomings identified with species richness and many of the other diversity indices (Warwick and Clarke 1995). They are based not only on the species abundances (denoted by x_i, the number of individuals of species i in the sample), but also on the taxonomic distances (ω_{ij}) through a classification tree between every pair of individuals (Fig. 9).

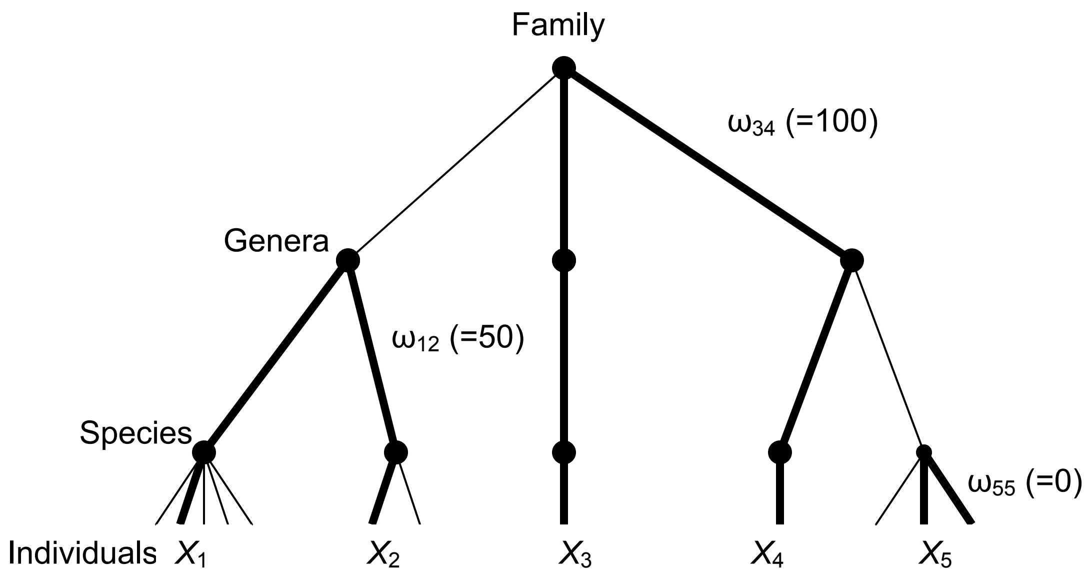


Figure 9. Hypothetical taxonomic tree for a sample consisting of 5 species, scaled such that the largest number of steps in the tree (the two species at the greatest taxonomic distance apart) is set to ω = 100. Redrawn from Clarke and Warwick (2001).

Average taxonomic diversity of a sample is then defined as:

$$\Delta = [\ \sum\sum_{i<j} \omega_{ij}\ x_i x_j\ ] \ /\ [N(N\text{-}1)/2] \qquad \text{Equation 2}$$

Where the double summation is over all pairs of species *i* and *j* (i,j = 1,2,….,*S*: $i<j$), and $N = \sum_i x_i$, the total number of individuals in the sample. Δ has a simple interpretation; it is the average 'taxonomic distance apart' of every pair of individuals in the sample, or stated another way, the expected path length between any two individuals drawn at random. In the hypothetical sample shown in Fig. 9, the distance between individuals in species 1 and 2 (drawn in bold lines) is ω_{12}= 50; between species 3 and 4 is ω_{34}=100; and between two individuals of species 5 is ω_{55}=0 (Clarke and Warwick 2001).When the taxonomic tree reduces to a single level hierarchy (all the species belong to a common genus), then Δ becomes:

$$\begin{aligned}\Delta^o &= [2 \sum\sum_{i<j}\ p_i p_j] \ /\ (1 - N^{-1}), \quad \text{where } p_i = x_i / N \\ &= (1 - \textstyle\sum_i p_i^2) \ /\ (1 - N^{-1}) \qquad \text{Equation 3}\end{aligned}$$

Equation 3 is a form of the Simpson diversity index. Δ can therefore be seen as a natural extension of Simpson, from the case where path length between individuals is either 0 (same species) or 100 (different species) or a more refined scale that captures the intervening relatedness values (0=same species, 20 different species in the same genera, 40=different genera but the same family, etc.; Clarke and Warwick 2001). In order to eliminate the dominating effect of the species abundance distribution $\{x_i\}$, leaving a distinctness measure that is more reflective of the overall taxonomic hierarchy, Warwick and Clarke (1995) recommend dividing Δ by the Simpson index Δ^o, to give average taxonomic distinctness:

$$\Delta^* = [\ \sum\sum_{i<j} \omega_{ij}\ x_i x_j] \ /\ [\ \sum\sum_{i<j}\ x_i x_j] \qquad \text{Equation 4}$$

One of the qualities of the taxonomic diversity (Δ) and average taxonomic distinctness (Δ^*) is that they are sample-size independent, inheriting this property from the Simpson index from which they are generalized. This fact can be exploited when comparing current data to historical datasets (albeit in their limited availabilities as noted in Contreras (2003a, 2003b, and 2003c) or for comparing different studies for which the sampling effort is unequal, uncontrolled, or unknown. The taxonomic diversity and distinctness measures will be primarily used for the biological data (nekton, benthic infauna, and aquatic insects). These measurements could ultimately be used as the building blocks for an Index of Biotic Integrity (IBI-type) measure that could be applied coast-wide to tidally influenced water bodies.

Assessment Methodology

The methodology for assessing ecosystem health and assigning site-specific uses and criteria within tidally influenced portions of river basin and coastal basin waters relies heavily on the non-parametric ordination techniques outlined in the previous section. Schematically, this methodology is shown in Fig. 10. In Part A, MDS procedures are used to identify the configurations of the different datasets (e.g., biological, physiochemical, habitat. etc.). Distinction among stations located on a common stream (in terms of its biological communities, physical, and chemical properties), as well as the differences among them in relation to the reference condition, must first be established. Here, the goal of the MDS is to assess any agreement between the biological “picture” and the more traditional physical and chemical “picture”. Spearman’s rank correlation is used to quantify the degree of agreement between the independent datasets (in Fig. 10, designation of 1, 2, and 3 in the hypothetical MDS plots represent the upper, middle, and lower station designations used for this study). The natural separation of the “biological” and the “physical and chemical” measurements are also evaluated with the same rank correlation method.

The biological communities are further assessed with the Average Taxonomic Distinctness measure. Any significant differences between the reference condition and the study streams are identified with the ANOSIM procedure. The ANOSIM procedure is valid for not only the biological communities, but also for the physical and chemical constituents as well. The variables most responsible for the separations seen in the ANOSIM are identified with the SIMPER procedure. From this, a suite of indicator taxa can be identified, and their sensitivity to variability in the physical and chemical datasets assessed. Core metrics that include information about the taxonomic breadth of the study locations can then be developed. The threshold (biocriteria) for discriminating between impaired and unimpaired conditions provides the basis for the assessment.

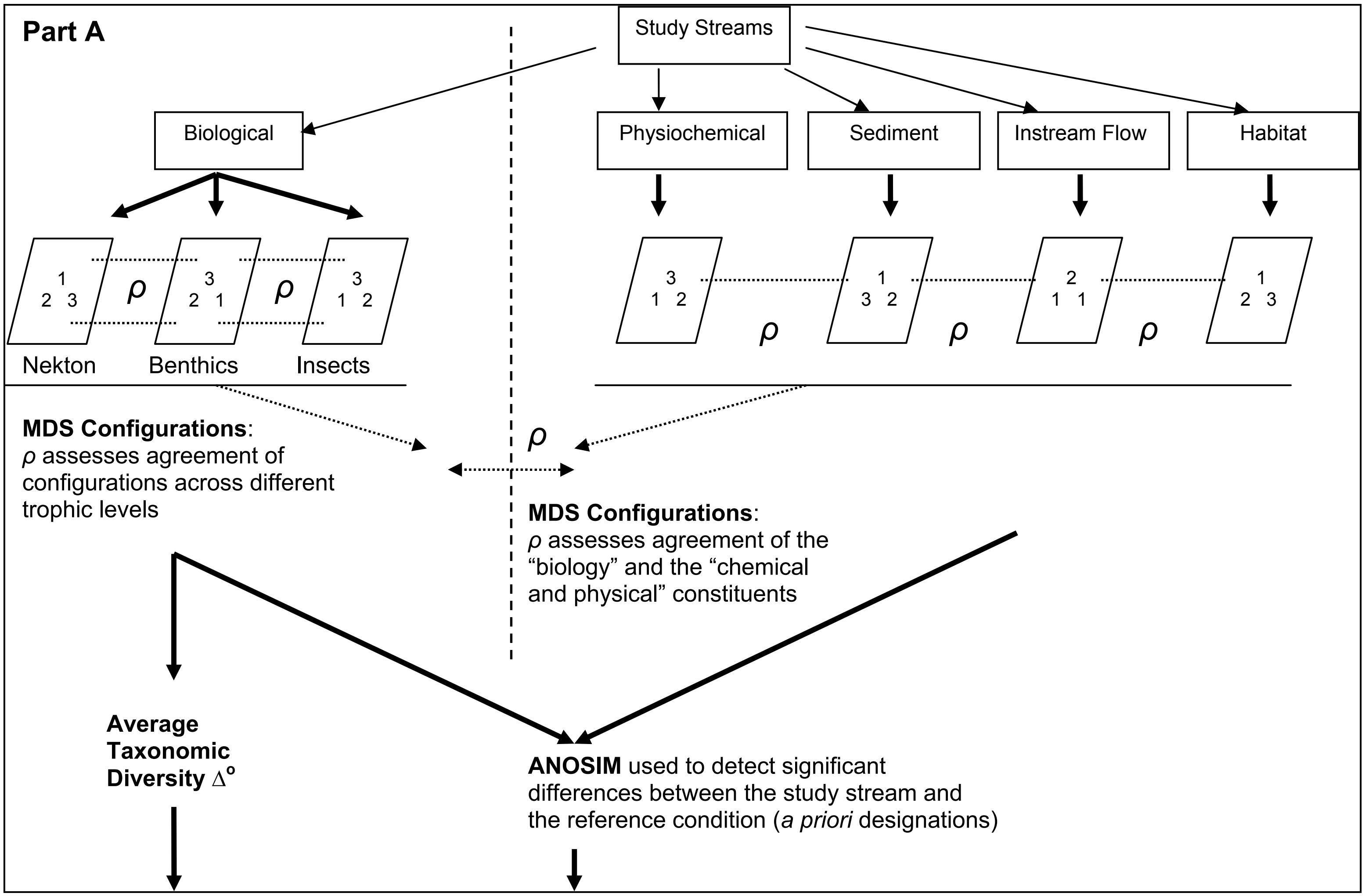


Figure 10. The process for assessing ecosystem health and determining biocriteria in tidally influenced streams.

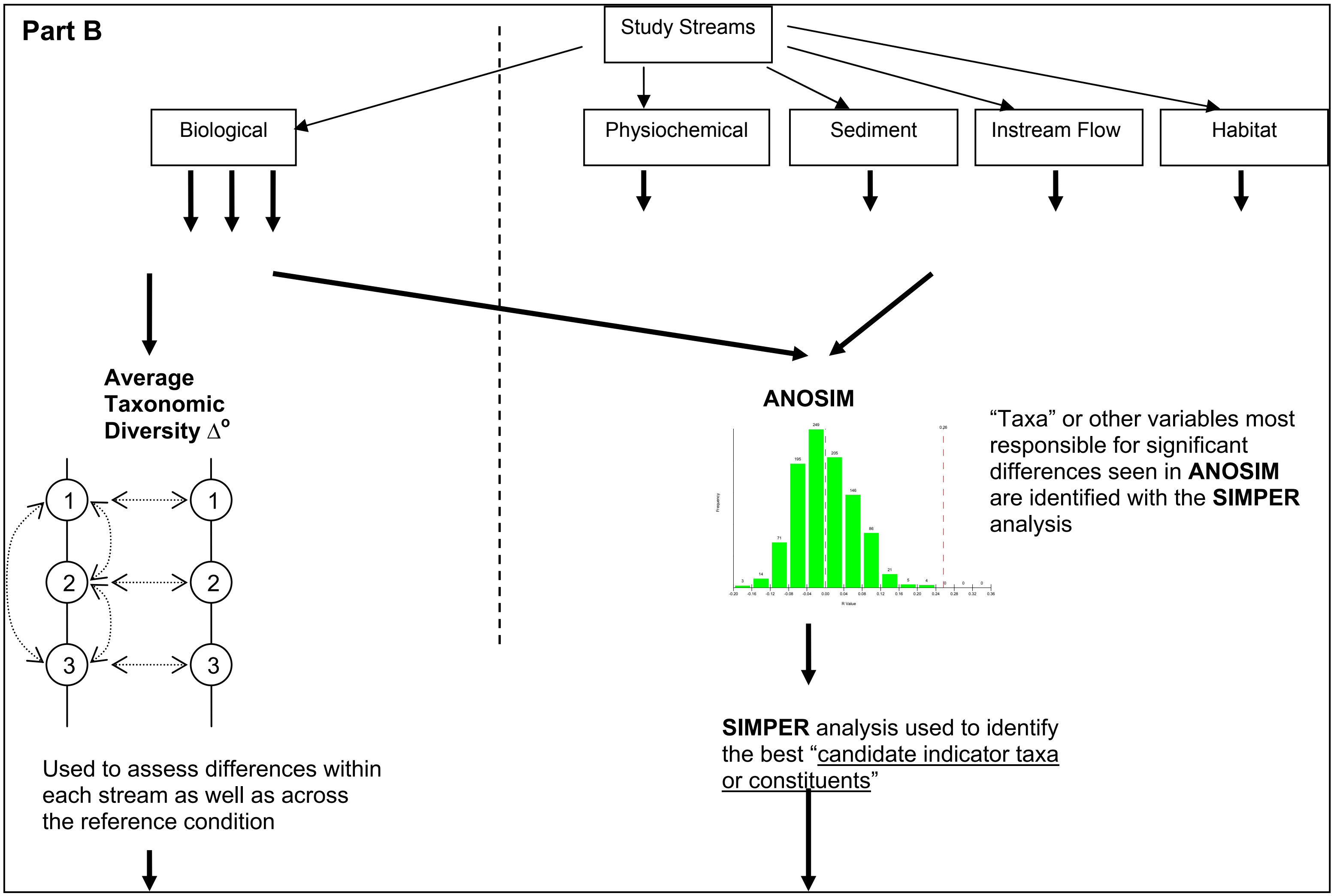


Figure 10. The process for assessing ecosystem health and determining biocriteria in tidal streams (continued).

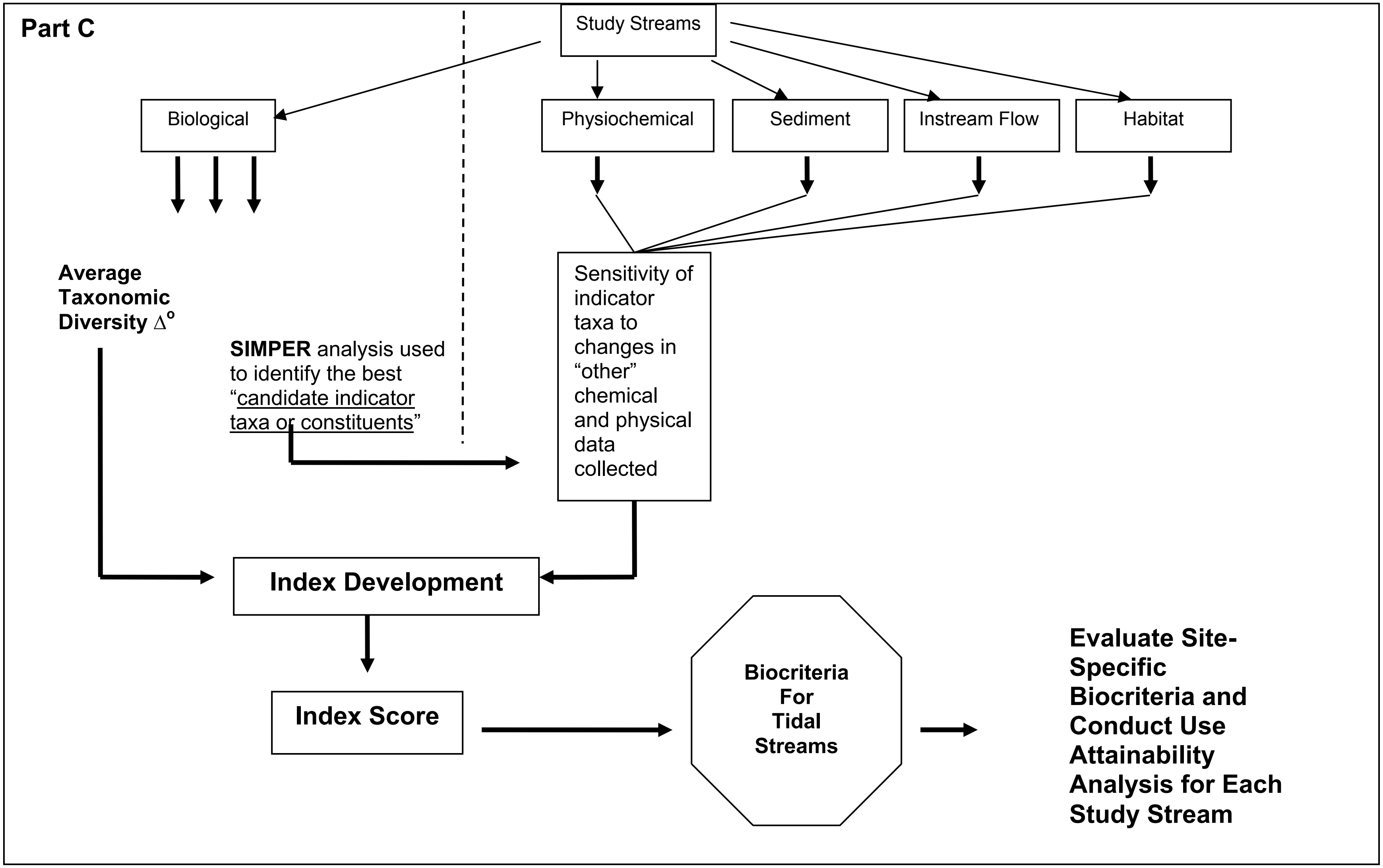


Figure 10. The process for assessing ecosystem health and determining biocriteria in tidal streams (continued).

RESULTS

Landcover Analysis

Tres Palacios

Classification of the surrounding watershed landcover into the 13 distinct thematic elements used for this study is presented in Table 17. Both absolute hectares and percentage of the watershed is presented. A comparison of the study stream to the reference stream is presented in Table 18, with numbers in parenthesis representing a smaller percentage in the references stream. Urban Index determination, in both absolute hectares and relative percentage, is presented in Table 19.

Table 17. Carancahua Creek and Tres Palacios River – Complete Watershed.

Class names	**Carancahua Creek**		**Tres Palacios River**		**% Change**
	Hectares	% Cover	Hectares	% Cover	Car-TP**
Agriculture	8343.0	37.9	32376.2	50.3	(12.3)
Evergreen	1864.1	8.5	8847.6	13.7	(5.3)
Grassland	4013.6	18.3	15007.6	23.3	(5.0)
Mesic Cold	13.8	0.1	530.2	0.8	(0.8)
Grass Farm	184.1	0.8	1020.7	1.6	(0.7)
Salt Prairie	110.4	0.5	443.6	0.7	(0.2)
Exposed Land	175.3	0.8	228.5	0.4	0.5
Marsh	263.5	1.2	364.0	0.6	0.6
Urban / Roads	175.8	0.8	56.5	0.1	0.7
Mixed Cold CD-EG*	631.9	2.9	1103.3	1.7	1.2
Open Water	1012.3	4.6	1405.6	2.2	2.4
Cold-deciduous	2088.2	9.5	149.1	0.2	9.3
Live Oak Forest	3115.0	14.2	2901.8	4.5	9.7
Total	21990.8		64434.4		

*Mixed Cold Deciduous – Ever Green
**This is the difference of percent covers between Carancahua and Tres Palacios.

Table 18. Carancahua Creek and Tres Palacios River – 200 meter Buffer of Stream Channel.

Class Name	**Carancahua Creek Buffer**		**Tres Palacios River Buffer**		**% Change**
	Hectares	% Cover	Hectares	% Cover	Car-TP
Agriculture	59.2	3.1	2821.4	37.0	(34.0)
Evergreen Shrubland	175.9	9.2	1271.8	16.7	(7.5)
Grassland	156.2	8.1	1321.6	17.3	(9.2)
Mesic Cold Deciduous Forest	1.3	0.1	225.3	3.0	(2.9)
Grass Farm	7.2	0.4	78.9	1.0	(0.7)
Salt Prairie	24.9	1.3	79.1	1.0	0.3
Exposed Land	49.7	2.6	30.6	0.4	2.2
Marsh	105.1	5.5	163.1	2.1	3.3
Urban / Roads	13.0	0.7	6.1	0.1	0.6
Mixed CD-EG* Shrubland	122.9	6.4	143.3	1.9	4.5
Open Water	437.0	22.7	487.4	6.4	16.3
Cold Deciduous Shrubland	159.5	8.3	57.6	0.8	7.5
Live Oak Forest	609.8	31.7	931.2	12.2	19.5
Total	1921.7		7,617.40		

*Mixed Cold Deciduous – Ever Green

Table 19. Carancahua Creek and Tres Palacios River – Urban Index.

	Carancahua Creek		**Tres Palacios River**	
	Hectares	% Total	Hectares	% Total
Urban Index	5652	25.60	13,566	20.94

Garcitas Creek

Watershed landcover classification for Garcitas Creek is presented in Table 20, with a comparison of the study stream to the reference stream presented in Table 21 (numbers in parenthesis representing a smaller percentage in the references stream). Urban Index determination, in both absolute hectares and relative percentage, is presented in Table 22.

Table 20. Carancahua Creek and Garcitas Creek – Complete Watershed.

Class names	Carancahua Creek Basin		Garcitas Creek Basin		% Change
	Hectares	% Cover	Hectares	% Cover	Car-Gar**
Agriculture	8343.0	37.9	9506.5	32.4	5.6
Evergreen Shrubland	1864.1	8.5	61.9	0.2	8.3
Grassland	4013.6	18.3	8674.6	29.5	(11.3)
Mesic Cold Deciduous Forest	13.8	0.1	0.0	0.0	0.1
Grass Farm	184.1	0.8	89.5	0.3	0.5
Salt Prairie	110.4	0.5	189.6	0.7	(0.2)
Exposed Land	175.3	0.8	68.5	0.2	0.6
Marsh	263.5	1.2	579.3	2.0	(0.8)
Urban / Roads	175.8	0.8	212.9	0.7	0.1
Mixed CD-EG* Shrubland	631.9	2.9	2779.2	9.5	(6.6)
Open Water	1012.3	4.6	717.0	2.4	2.2
Cold-deciduous Shrubland	2088.2	9.5	84.4	0.3	9.2
Live Oak Forest	3115.0	14.2	3822.9	13.0	1.2
Upland Cold-Deciduous Forest	0.0	0.0	385.3	1.3	(1.3)
Huisache - Mesquite Shrubland	0.0	0.0	2196.9	7.5	(7.5)
Totals	21990.8		29368.5		

*Mixed Cold Deciduous – Ever Green
** This is the difference of percent covers between Carancahua and Garcitas.

Table 21. Carancahua Creek and Garcitas – 200 meter Buffer of Stream Channel.

Class Name	**Carancahua Creek Buffer**		**Garcitas Creek Buffer**		**% Change**
	Hectares	% Cover	Hectares	% Cover	Car-Gar
Agriculture	59.2	3.1	148.7	4.8	(1.7)
Evergreen Shrubland	175.9	9.2	10	0.3	8.8
Grassland	156.2	8.1	435.7	14.0	(5.8)
Mesic Cold Deciduous Forest	1.3	0.1		0.0	0.1
Grass Farm	7.2	0.4	0.5	0.0	0.4
Salt Prairie	24.9	1.3	39.7	1.3	0.0
Exposed Land	49.7	2.6	7.8	0.2	2.3
Marsh	105.1	5.5	173	5.5	(0.1)
Urban / Roads	13	0.7	19.4	0.6	0.1
Mixed CD-EG* Shrubland	122.9	6.4	437.2	14.0	(7.6)
Open Water	437	22.7	238.6	7.6	15.1
Cold-deciduous Shrubland	159.5	8.3	27.9	0.9	7.4
Live Oak Forest	609.8	31.7	1,279.30	41.0	(9.3)
Upland Cold Deciduous Forest		0.0	172	5.5	(5.5)
Huisache-Mesquite Shrubland		0.0	131.1	4.2	(4.2)
Total	1921.7		3120.9		

*Mixed Cold Deciduous – Ever Green

Table 22. Carancahua Creek and Garcitas – Urban Index

	Carancahua Creek		**Garcitas Creek**	
	Hectares	% Total	Hectares	% Total
Urban Index	5652	25.60	7855	26.68

Instream and Riparian Habitat Classification Results

Tres Palacios and Carancahua Creeks

Average thalweg (maximum channel depth) measurements were fairly similar for these two streams (Table 23). Tres Palacios had an overall average thalweg of 3.1 ± 1.1 m, and Carancahua had an average thalweg of 3.3 ± 0.9 m. Systematic measurements of shoreline depths for each stream reach revealed that both streams showed similar patterns along their shoreline edges, as well. Depths along the sides of channels in both streams were greatest at the uppermost sampling reaches (Tres Palacios reach 1 = 1.8 ± 0.2 m; Carancahua reach 1 = 1.6 ± 0.5 m) and these channel-side depths decreased to their respective lower sampling reaches nearest the bay (Tres Palacios reach 3 = 0.4 ± 0.2 m; Carancahua reach 3 = 0.5 ± 0.2 m). In-channel habitat for both streams was characterized either as pools or glides, and the number of side channels per 100 m generally did not change from the upper to lower sites in both streams. Similarly, the number of snags (a measure of fish cover complexity) along the bottom also decreased from the upper to lower reach of each stream.

Very little large woody debris was found in either stream, less than 1 piece per 100 m (Table 23). Both streams had an overall average of 0.5 pieces of large woody debris per 100 m.

Wetted and bankfull channel width measurements showed similar patterns for both streams with both growing wider from the upstream to downstream reaches (Table 23). Tres Palacios wetted width ranged from 36.6 ± 3.0 m at reach 1 to 201.5 ± 97.3 m at reach 3. Likewise, wetted widths for Carancahua ranged from 34.8 ± 2.8 m at reach 1 to 386.0 ± 434.5 m at reach 3. Bankfull widths were nearly the same as wetted widths in these two streams. Average bankfull height for both streams was between 0.3 to 0.4 m above the water line. However, channel incised heights for both streams were slightly greater than their respective bankfull heights at their upper and middle reaches (reaches 1 and 2). Both streams showed a progressive decrease in the degree of channel incision from their uppermost reach (reach 1) down to their downstream reach (reach 3). This observation was also reflected in the measurements of bank angles along the stream reaches. For both streams, bank angles in their upper reaches were characterized as steep (between 30 and 75º), middle reaches were characterized as gradual (between 5 and 30º), and lower reaches were characterized as flat (<5º) or gradual. Overall channel sinuosity was similar for both streams, though there was some variability between reaches within streams.

Table 23. Channel characteristics by reach for Tres Palacios River and Carancahua Creek. Data are means (n=11). Standard deviations are presented in parentheses. Overall means and standard deviations are also included below each reach's statistics (n=33).

Stream	Reach	Thalweg (m)	Sinuosity	Shoreline Depth (m)	Wetted Width (m)	Bankfull Width (m)	Bankfull Height (m)	Incised Height (m)	Bank Angle (degrees)	Side channels (No./100m)	Snags (No./100m)	Large Woody Debris (No./100m)
Tres Palacios	1	3.6 (0.6)	1.4	1.8 (0.2)	36.6 (3.0)	36.7 (3.3)	0.3 (0.0)	1.0 (0.4)	46.1 (21.1)	0.1	0.8	0.9
Tres Palacios	2	3.6 (0.5)	1.2	1.1 (0.3)	54.2 (4.9)	54.9 (4.8)	0.3 (0.0)	0.9 (0.4)	27.0 (16.3)	0.1	0.6	0.0
Tres Palacios	3	1.9 (0.9)	1.2	0.4 (0.2)	201.5 (97.3)	202.8 (97.2)	0.3 (0.0)	0.3 (0.0)	3.9 (4.5)	0.2	0.0	0.5
MEAN		3.1 (1.1)	1.3	1.1 (0.6)	97.5 (92.8)	98.2 (93.1)	0.3 (0.0)	0.7 (0.4)	25.7 (23.2)	0.1	0.4	0.5
Carancahua	1	3.9 (0.4)	1.4	1.6 (0.5)	34.8 (2.8)	35.5 (3.4)	0.5 (0.0)	1.9 (0.6)	49.3 (10.6)	0.3	1.0	0.5
Carancahua	2	3.7 (0.4)	1.2	1.6 (0.4)	41.4 (4.1)	42.2 (4.3)	0.4 (0.1)	0.9 (0.2)	12.0 (7.6)	0.3	0.9	0.9
Carancahua	3	2.3 (0.9)	1.7	0.5 (0.2)	386.0 (434.5)	387.0 (434.2)	0.3 (0.0)	0.3 (0.0)	6.6 (7.0)	0.3	0.0	0.0
MEAN		3.3 (0.9)	1.4	1.2 (0.6)	154.1 (294.5)	154.9 (294.5)	0.4 (0.1)	1.0 (0.7)	22.7 (21.0)	0.3	0.6	0.5

Dominant bottom substrate types measured during thalweg sampling were different for the two streams (Table 24). For Tres Palacios, the majority (73%) of substrates measured were generally in the "fines" category which include silt and/or clay materials (<0.6 mm, not gritty). Conversely, most substrates (71%) in Carancahua were in the sand category (0.6 to 2 mm, gritty). However, both streams showed a pattern of increasing content of fine materials in their sediments from their respective upstream to downstream reaches. Gravel sized materials (2 to 64 mm) were found along almost all reaches of both steams and accounted for a sizable percentage of the bottom substrates measured for Tres Palacios reach 1 (46%) and Carancahua reach 3 (30%), only reach 3 of Tres Palacios had no gravel found along its thalweg during sampling. Also, some cobble sized materials (64 – 250 mm) were found along reach 1 of Tres Palacios.

As with the results for thalweg sediments, the dominant shoreline and shallow nearshore substrate types were different for these two streams (Table 24). Sampling sites of Tres Palacios were dominated (100%) by fine materials along their banks and shallow edges, while those for Carancahua were dominated mostly by sand material (85%) with some fine materials (15%) present.

Canopy densities of the riparian habitat along sides of these streams, as measured using a densiometer, showed similar patterns for both streams (Table 25). Canopy density decreased from upper to lower stream reaches. Canopy densities at reach 1 of Tres Palacios were 80% and declined to 3% at reach 3. Likewise, canopy densities in Carancahua declined from reach 1 (96%) to reach 3 (2%).

Visual estimates of riparian vegetative cover reflected similar results. Overall plant cover decreased from upper to lower reaches of both streams (Table 25). For Tres Palacios, total vegetative cover at reach 1 was 135% (coverage from canopy, understory and ground cover layers summed to > 100%), but declined to 92% at reach 3. In similar fashion, Carancahua had total vegetative cover of 124% at reach 1 and this declined to 93% at reach 3. Large and small trees were most prevalent in the uppermost reaches of both streams and decreased in percent cover in downstream sites. This same pattern was also loosely followed for woody understory and ground cover along these two streams. Conversely, herbaceous cover in the understory increased in downstream reaches, but herbaceous cover at ground level either decreased (Tres Palacios) or followed no clear pattern (Carancahua) from upstream to downstream reaches. Overall though, upstream sites were more forested while downstream sites were more open and dominated by herbaceous species such as grasses.

Table 24. Dominant channel and shoreline substrate composition by reach for Tres Palacios River and Carancahua Creek. Data are means (n=11). Overall means are also included below each reach's statistics (n=33). The cobble and gravel category is presented only for channel bottom statistics.

		Thalweg				Shallow Nearshore		Shoreline	
Stream	**Reach**	Cobble (%)	Gravel (%)	Sand (%)	Fines (%)	Sand (%)	Fines (%)	Sand (%)	Fines (%)
Tres Palacios	1	3	46	9	42	0	100	0	100
Tres Palacios	2	0	14	6	80	0	100	0	100
Tres Palacios	3	0	0	4	96	0	100	0	100
MEAN		1	20	6	73	0	100	0	100
Carancahua	1	0	6	94	0	100	0	100	0
Carancahua	2	0	5	93	2	91	9	91	9
Carancahua	3	0	30	26	44	64	36	64	36
MEAN		0	14	71	15	85	15	85	15

Table 25. Canopy density and percent vegetative cover by reach for riparian habitats along Tres Palacios River and Carancahua Creek. Data are means with standard deviations in parentheses (n=11). Overall means and standard deviations are also included below each reach's statistics (n=33).

Stream	**Reach**	**Canopy Density (%)**	**Canopy**		**Understory**		**Ground cover**			**TOTAL COVER**
			Big Trees	Small Trees	Woody Shrubs	Herbs, Grass, Forbs	Woody Shrubs	Herbs, Grass, Forbs	Bare/ Duff	
Tres Palacios	1	80 (22)	22 (13)	23 (8)	20 (5)	22 (11)	5 (0)	44 (10)	19 (10)	135
Tres Palacios	2	48 (35)	11 (11)	19 (8)	18 (12)	23 (6)	5 (0)	40 (15)	11 (8)	115
Tres Palacios	3	3 (10)	0 (0)	1 (4)	18 (12)	52 (17)	6 (13)	14 (10)	4 (2)	92
MEAN		44 (40)	11 (13)	14 (12)	19 (10)	32 (19)	5 (8)	33 (18)	11 (10)	114
Carancahua	1	96 (12)	20 (7)	24 (9)	31 (17)	22 (8)	7 (8)	21 (8)	16 (8)	124
Carancahua	2	39 (44)	12 (14)	19 (12)	12 (7)	23 (15)	5 (1)	26 (19)	15 (13)	96
Carancahua	3	2 (3)	1 (4)	3 (6)	28 (17)	35 (17)	6 (3)	19 (18)	3 (7)	93
MEAN		46 (47)	11 (12)	15 (13)	24 (16)	26 (15)	6 (5)	22 (15)	12 (11)	104

Both streams were very similar in terms of the total amount of fish cover found in the shallow areas of their upper, mid, and lower reaches, but they differed somewhat in terms of the composition of that fish cover. (Table 26). Fish cover in Tres Palacios was highest at reach 1 with a total cover of 57%, a decline to 38% at reach 2, and a further decline to 25% for reach 3. Likewise, Carancahua had a total fish cover of 54% at reach 1, 39% for reach 2, and 19% for reach 3. All of this fish cover was composed of natural materials for both streams. The majority of the fish cover for reach 1 and 2 of Tres Palacios was fairly evenly split between small woody debris or overhanging woody vegetation within 1 m of the water's surface. However, for reach 3 of Tres Palacios, most of the fish cover was created by emergent macrophytes. Conversely, overhanging woody vegetation accounted for the majority of fish cover for reaches 1 and 2 of Carancahua. Fish cover for reach 3 of Carancahua was split among a number of different cover types, though macrophyte cover was the largest cover type. As also reflected in riparian vegetation measurements, fish cover appeared to transition from woody material at reaches 1 and 2 to more herbaceous materials in reach 3 of both streams.

The overall degree of human influence observed in Tres Palacios was slightly greater than for Carancahua (Table 27). Pasture, range, and hay fields were by far the most common signs of human influence in both streams, being observed at 82% of samplings sites in Tres Palacios and 61% of sites in Carancahua. Power lines were the second most common sign of human influence seen in both streams with Tres Palacios having them at 39% of its sampling sites and Carancahua having them at 24% of its sites. Buildings were observed from 24% of sites along Tres Palacios versus 15% of Carancahua sites. Walls, dikes, revetments, riprap or dams were observed at 18% of Tres Palacios sampling locations, but only 6% of the time in Carancahua. Roads and/or railroads were observed from 14% of Tres Palacios sampling sites and 12% of Carancahua sites. Parks or lawns were observed from 12% of Tres Palacios sites and 9% of Carancahua sites. Overall, signs of human influence for both streams appear to be chiefly associated with cattle grazing. Using a weighted averaging method outlined in Kaufmann et al. (1999) which accounts not only for the presence of these human disturbances but also their distance from the sampling area, Tres Palacios appeared to be more impacted by human influences. Tres Palacios' overall average degree of human influence was 1.10 and Carancahua's was 0.69. This index number should be viewed simply as a comparative value used to relate these two streams to each other with no broader context to other streams.

Table 26. Percent fish cover by reach for Tres Palacios River and Carancahua Creek. Data are means with standard deviations in parentheses (n=11). Overall means and standard deviations are also included below each reach's statistics (n=33).

Stream	Reach	Filamentous Algae	Macrophytes	Large Woody Debris	Small Woody Debris	Live Trees in Stream	Overhanging Vegetation	Undercut Banks	Boulders/ Ledges	Artificial Structures	TOTAL COVER
Tres Palacios	1	3 (3)	1 (2)	1 (2)	20 (9)	4 (7)	23 (15)	5 (0)	0 (0)	0 (2)	57
Tres Palacios	2	4 (2)	4 (7)	0 (0)	13 (17)	4 (7)	10 (17)	4 (2)	0 (0)	0 (2)	38
Tres Palacios	3	1 (2)	19 (16)	0 (2)	4 (2)	0 (0)	0 (0)	0 (2)	0 (0)	0 (0)	25
MEAN		3 (3)	8 (13)	0 (1)	12 (13)	3 (6)	11 (16)	3 (2)	0 (0)	0 (1)	40
Carancahua	1	0 (0)	7 (17)	0 (2)	9 (8)	0 (0)	33 (21)	5 (2)	0 (0)	0 (0)	54
Carancahua	2	0 (0)	3 (3)	0 (2)	11 (17)	0 (2)	20 (21)	4 (2)	0 (0)	0 (0)	39
Carancahua	3	0 (0)	8 (8)	0 (0)	5 (7)	0 (0)	2 (3)	3 (3)	0 (0)	0 (2)	19
MEAN		0 (0)	6 (11)	0 (1)	8 (11)	0 (1)	18 (21)	4 (2)	0 (0)	0 (1)	37

Table 27. Percent frequency of occurrence of human influences by reach for Tres Palacios and Carancahua Creeks. Data are means (n=11). Overall means are also included below each reach's statistics (n=33).

Stream	Reach	Wall/Dike/ Revetment/ Riprap/Dam	Buildings	Pavement/ Cleared Lot	Road/ Railroad	Pipes	Landfill/ Trash	Park/ Lawn	Row Crops	Pasture/ Range/ Hay	Logging	Mining	Power Lines	Weighted Average – All Human Influence*
Tres Palacios	1	18	14	5	5	0	9	14	0	77	0	0	9	1.03
Tres Palacios	2	27	14	9	9	0	0	14	0	95	0	0	68	1.35
Tres Palacios	3	9	45	5	27	0	0	9	5	73	0	0	41	0.93
MEAN		18	24	6	14	0	3	12	2	82	0	0	39	1.10
Carancahua	1	0	0	0	0	0	0	0	0	50	0	0	0	0.30
Carancahua	2	0	5	0	14	0	0	5	0	77	0	0	5	0.76
Carancahua	3	18	41	5	23	0	0	23	0	55	0	0	68	1.01
MEAN		6	15	2	12	0	0	9	0	61	0	0	24	0.69

* For a detailed description of the procedure used for weighting human influences see Kaufmann et al. 1999.

Garcitas and Carancahua Creeks

Average thalweg (maximum channel depth) measurements were fairly similar for these two streams. (Table 28). Garcitas had an overall average thalweg measurement of 3.2 ± 0.9 m, and Carancahua had an average thalweg of 3.3 ± 0.9 m. Systematic measurements of shoreline depths for each stream reach revealed that both streams showed similar patterns along their shoreline edges, as well. Depths along the sides of channels in both streams were greatest at the uppermost sampling reaches (Garcitas reach 1 = 1.3 ± 0.5 m; Carancahua reach 1 = 1.6 ± 0.5 m) and these channel-side depths decreased to their respective lower sampling reaches nearest the bay (Garcitas reach 3 = 1.1 ± 0.9 m; Carancahua reach 3 = 0.5 ± 0.2 m). In-channel habitat for both streams was characterized either as pools or glides, and the number of side channels per 100 m did not change from the upper to lower sites in both streams. The number of snags (a measure of fish cover complexity) along the bottom decreased from the upper to lower reach of each stream.

Garcitas had more large woody debris than Carancahua (Table 28). On average 1.7 pieces of woody debris were found per 100m in Garcitas, while only 0.5 pieces were found per 100 m in Carancahua.

Wetted and bankfull channel width measurements were different for the two streams (Table 28). Garcitas wetted width at reach 1 was 72.3 ± 20.7 m, then decreased to 61.4 ± 10.1 at reach 2, and then increased to 88.7 ± 16.4 m at reach 3. Conversely, wetted widths for Carancahua were from 34.8 ± 2.8 m at reach 1 to 386.0 ± 434.5 m at reach 3, and increased in width moving further downstream. Bankfull widths followed the same patterns seen for each stream's respective wetted widths. Average bankfull height for both streams ranged from 0.6 to 0.4 m above the water line. However, channel incised heights for both streams were greater than their respective bankfull heights at their upper and middle reaches, and also for reach 3 at Garcitas. Both streams showed a progressive decrease in the degree of channel incision from their uppermost reach (reach 1) down to their downstream reach (reach 3). Channel incision observations were also reflected in the measurements of bank angles along the stream reaches. For both streams, average bank angles at all reaches were characterized as either steep (between 30 and 75º) or gradual (between 5 and 30º). Overall channel sinuosity was similar for both streams, though there was some variability between reaches within streams.

Table 28. Channel characteristics by reach for Garcitas and Carancahua Creeks. Data are means (n=11). Standard deviations are presented in parentheses. Overall means and standard deviations are also included below each reach's statistics (n=33).

Stream	Reach	Thalweg (m)	Sinuosity	Shoreline Depth (m)	Wetted Width (m)	Bankfull Width (m)	Bankfull Height (m)	Incised Height (m)	Bank Angle (degrees)	Side channels (No./100m)	Snags (No./100m)	Large Woody Debris (No./100m)
Garcitas	1	2.7 (0.8)	2.2	1.3 (0.5)	72.3 (20.7)	73.8 (20.1)	0.9 (0.2)	2.0 (0.6)	27.0 (16.3)	0.0	1.2	3.2
Garcitas	2	3.6 (0.6)	1.4	1.2 (0.5)	61.4 (10.1)	63.3 (9.5)	0.5 (0.2)	1.5 (0.8)	24.3 (19.0)	0.0	0.5	1.4
Garcitas	3	3.4 (0.8)	1.2	1.1 (0.9)	88.7 (16.4)	89.8 (16.8)	0.3 (0.0)	0.5 (0.3)	18.9 (27.3)	0.0	0.2	0.5
MEAN		3.2 (0.9)	1.6	1.2 (0.6)	74.1 (19.5)	75.6 (19.1)	0.6 (0.3)	1.3 (0.9)	23.4 (21.0)	0.0	0.6	1.7
Carancahua	1	3.9 (0.4)	1.4	1.6 (0.5)	34.8 (2.8)	35.5 (3.4)	0.5 (0.0)	1.9 (0.6)	49.3 (10.6)	0.3	1.0	0.5
Carancahua	2	3.7 (0.4)	1.2	1.6 (0.4)	41.4 (4.1)	42.2 (4.3)	0.4 (0.1)	0.9 (0.2)	12.0 (7.6)	0.3	0.9	0.9
Carancahua	3	2.3 (0.9)	1.7	0.5 (0.2)	386.0 (434.5)	387.0 (434.2)	0.3 (0.0)	0.3 (0.0)	6.6 (7.0)	0.3	0.0	0.0
MEAN		3.3 (0.9)	1.4	1.2 (0.6)	154.1 (294.5)	154.9 (294.5)	0.4 (0.1)	1.0 (0.7)	22.7 (21.0)	0.3	0.6	0.5

Dominant bottom substrate types measured during thalweg sampling were generally similar for the two streams (Table 29). Both streams had bottom substrates composed primarily of sand (0.6 to 2 mm, gritty). For Garcitas, 77% of all bottom substrates measured were sand, while 71% of bottom substrates in Carancahua were in the sand category. However, both streams showed a pattern of increasing content of fine materials (<0.6 mm, not gritty) in their sediments from their respective upstream to downstream reaches. Gravel sized materials (2 to 64 mm) were found along parts of every reach of both steams being present at 6% of sites in Garcitas and 14% of sites in Carancahua. Also, some cobble sized materials (64 – 250 mm) were found along reach 3 of Garcitas (7% of sites).

Unlike the results for thalweg sediments, the dominant shoreline and shallow nearshore substrate types were different for these two streams (Table 29). Sampling sites of Garcitas were fairly evenly split between fines (51%) and sand (43%), while Carancahua had mostly sandy sediments (85%) with some fine materials (15%) present. This average for Garcitas is slightly skewed do to the fact that the upper two stations were 63% to 64% sand with the lower station being 0% sand.

Canopy densities of the riparian habitat along sides of these streams, as measured using a densiometer, showed similar patterns for both streams (Table 30). Canopy density decreased from upper to lower stream reaches. Canopy densities at reach 1 of Garcitas were 61% and declined to 8% at reach 3. Likewise, canopy densities in Carancahua declined from reach 1 (96%) to reach 3 (2%).

Visual estimates of riparian vegetative cover reflected similar results. Overall plant cover decreased from upper to lower reaches of both streams (Table 30). For Garcitas, total vegetative cover at reach 1 was 124% (coverage from canopy, understory and ground cover layers summed to > 100%), but declined to 89% at reach 3. In similar fashion, Carancahua had total vegetative cover of 124% at reach 1 and this declined to 93% at reach 3. Large and small trees were most prevalent in the uppermost reaches of both streams and decreased in percent cover in downstream sites. Conversely, herbaceous cover in the understory increased in downstream reaches, but herbaceous cover at ground level either decreased (Garcitas) or followed no clear pattern (Carancahua) from upstream to downstream reaches. Overall though, upstream sites were more forested while downstream sites were more open and dominated by herbaceous species such as grasses.

Table 29. Dominant channel and shoreline substrate composition by reach for Garcitas and Carancahua Creeks. Data are means (n=11). Overall means are also included below each reach's statistics (n=33). The cobble category is presented only for channel bottom statistics, and the other category (i.e., a concrete structure) is only presented for shallow nearshore and shoreline statistics.

Stream	Reach	THALWEG				SHALLOW NEARSHORE				SHORELINE			
		Cobble (%)	Gravel (%)	Sand (%)	Fines (%)	Gravel (%)	Sand (%)	Fines (%)	Other (%)	Gravel (%)	Sand (%)	Fines (%)	Other (%)
Garcitas	1	0	1	96	3	0	64	36	0	0	64	36	0
Garcitas	2	0	8	86	6	0	64	36	0	0	64	36	0
Garcitas	3	7	8	49	36	9	0	82	9	9	0	82	9
MEAN		2	6	77	15	3	43	51	3	3	43	51	3
Carancahua	1	0	6	94	0	0	100	0	0	0	100	0	0
Carancahua	2	0	5	93	2	0	91	9	0	0	91	9	0
Carancahua	3	0	30	26	44	0	64	36	0	0	64	36	0
MEAN		0	14	71	15	0	85	15	0	0	85	15	0

Table 30. Canopy density and percent vegetative cover by reach for riparian habitats along Garcitas and Carancahua Creeks. Data are means with standard deviations in parentheses (n=11). Overall means and standard deviations are also included below each reach's statistics (n=33).

Stream	Reach	Canopy Density (%)	Canopy		Understory		Ground cover			TOTAL COVER
			Big Trees	Small Trees	Woody Shrubs	Herbs, Grass, Forbs	Woody Shrubs	Herbs, Grass, Forbs	Bare/ Duff	
Garcitas	1	61 (41)	26 (18)	12 (10)	16 (11)	17 (17)	6 (7)	47 (17)	14 (10)	124
Garcitas	2	40 (42)	17 (21)	17 (9)	17 (9)	16 (7)	6 (3)	48 (12)	18 (13)	121
Garcitas	3	8 (21)	0 (0)	3 (5)	26 (13)	31 (19)	5 (1)	24 (16)	12 (13)	89
MEAN		37 (41)	14 (19)	10 (10)	20 (12)	22 (16)	6 (5)	40 (18)	15 (12)	112
Carancahua	1	96 (12)	20 (7)	24 (9)	31 (17)	22 (8)	7 (8)	21 (8)	16 (8)	124
Carancahua	2	39 (44)	12 (14)	19 (12)	12 (7)	23 (15)	5 (1)	26 (19)	15 (13)	96
Carancahua	3	2 (3)	1 (4)	3 (6)	28 (17)	35 (17)	6 (3)	19 (18)	3 (7)	93
MEAN		46 (47)	11 (12)	15 (13)	24 (16)	26 (15)	6 (5)	22 (15)	12 (11)	104

Both streams showed similar patterns in terms of the total amount of fish cover found in the shallow areas of their upper, mid, and lower reaches, but differed in terms of the actual values for these measures (Table 31). Fish cover in Garcitas was highest at reach 1 with a total cover of 83%, a decline to 35% at reach 2, and a further decline to 22% for reach 3. Likewise, Carancahua had a total fish cover of 54% at reach 1, 39% for reach 2, and 19% for reach 3. Almost all of this fish cover was composed of natural materials for both streams. The majority of the fish cover for reach 1 and 2 of Garcitas was fairly evenly split between small woody debris or overhanging woody vegetation within 1 m of the water's surface. However, for reach 3 of Garcitas, most of the fish cover was created by emergent macrophytes. Conversely, overhanging woody vegetation accounted for the majority of fish cover for reaches 1 and 2 of Carancahua. Fish cover for reach 3 of Carancahua was split among a number of different cover types, though macrophyte cover was the largest cover type. As also reflected in riparian vegetation measurements, fish cover appeared to transition from woody material at reaches 1 and 2 to more herbaceous materials in reach 3 of both streams.

The overall degree of human influence observed in Garcitas was slightly lower than for Carancahua (Table 32). Pasture, range, and hay fields were by far the most common signs of human influence in both streams, being observed at 33% of samplings sites in Garcitas and 61% of sites in Carancahua. Power lines were the second most common sign of human influence for Carancahua at 24%, but power lines and roads/railroads tied for the second most common sign of human influence in Garcitas (both at 12%). Roads and railroads were seen at 12% of sampling sites for Carancahua, as well. Buildings were observed from 9% of sites along Garcitas versus 15% of Carancahua sites. Walls, dikes, revetments, riprap or dams were observed at 11% of Garcitas sampling locations, but only 6% of the time in Carancahua. Parks or lawns were observed from 8% of Garcitas sites and 9% of Carancahua sites. Overall, signs of human influence for both streams appear to be chiefly associated with cattle grazing. A weighted averaging method outlined in Kaufmann et al. (1999) which accounts not only for the presence of these human disturbances but also their distance from the transects, also showed that Carancahua appeared to be more impacted by human influences. Garcitas' overall average degree of human influence was 0.46 versus Carancahuas' 0.69. This index number should be viewed simply as a comparative value used to relate these two streams to each other with no broader context to other streams.

Table 31. Percent fish cover by reach for Garcitas and Carancahua Creeks. Data are means with standard deviations in parentheses (n=11). Overall means and standard deviations are also included below each reach's statistics (n=33).

Stream	Reach	Filamentous Algae	Macrophytes	Large Woody Debris	Small Woody Debris	Live Trees in Stream	Overhanging Vegetation	Undercut Banks	Boulders/ Ledges	Artificial Structures	TOTAL COVER
Garcitas	1	0 (0)	0 (2)	2 (3)	30 (30)	1 (2)	37 (24)	13 (17)	0 (0)	0 (0)	83
Garcitas	2	0 (0)	6 (10)	1 (2)	12 (18)	0 (0)	10 (10)	6 (7)	0 (0)	0 (0)	35
Garcitas	3	0 (0)	11 (11)	0 (0)	3 (3)	0 (0)	2 (3)	2 (3)	0 (0)	5 (10)	22
MEAN		0 (0)	6 (9)	1 (2)	15 (23)	0 (1)	16 (21)	7 (11)	0 (0)	2 (6)	47
Carancahua	1	0 (0)	7 (17)	0 (2)	9 (8)	0 (0)	33 (21)	5 (2)	0 (0)	0 (0)	54
Carancahua	2	0 (0)	3 (3)	0 (2)	11 (17)	0 (2)	20 (21)	4 (2)	0 (0)	0 (0)	39
Carancahua	3	0 (0)	8 (8)	0 (0)	5 (7)	0 (0)	2 (3)	3 (3)	0 (0)	0 (2)	19
MEAN		0 (0)	6 (11)	0 (1)	8 (11)	0 (1)	18 (21)	4 (2)	0 (0)	0 (1)	37

Table 32. Percent frequency of occurrence of human influences by reach for Garcitas and Carancahua Creeks. Data are means (n=11). Overall means are also included below each reach's statistics (n=33).

Stream	Reach	Wall/Dike/ Revetment/ Riprap/Dam	Buildings	Pavement/ Cleared Lot	Road/ Railroad	Pipes	Landfill/ Trash	Park/ Lawn	Row Crops	Pasture/ Range/ Hay	Logging	Mining	Power Lines	Weighted Average – All Human Influence*
Garcitas	1	5	9	0	14	0	0	9	0	14	0	0	9	0.28
Garcitas	2	0	0	0	9	0	14	0	0	64	0	0	0	0.42
Garcitas	3	27	18	5	14	0	0	14	0	23	0	0	27	0.69
MEAN		11	9	2	12	0	5	8	0	33	0	0	12	0.46
Carancahua	1	0	0	0	0	0	0	0	0	50	0	0	0	0.30
Carancahua	2	0	5	0	14	0	0	5	0	77	0	0	5	0.76
Carancahua	3	18	41	5	23	0	0	23	0	55	0	0	68	1.01
MEAN		6	15	2	12	0	0	9	0	61	0	0	24	0.69

* For a detailed description of the procedure used for weighting human influences see Kaufmann et al. 1999.

Instream Flow Characterization

Flow data (discharge and velocity) was recorded in three tidal streams on the mid-Texas coast. The coastal streams studied are small, with limited channel inputs between stations. Instantaneous discharge measurements (ADCP data) were collected at all study sites, when possible, during 12 sampling events between April 2003 and November 2004. Generally, replicate measures of flow were not sufficiently consistent (within the USGS recommended 5% agreement) to calculate mean discharge with confidence according to USGS procedures. However, recognizing the dynamic nature of tidal streams and the difficulty associated with obtaining accurate measures of flow, mean discharge was calculated based on all reasonable recorded estimates of stream discharge (AbsQ) to provide a general estimate of mean discharge (cfs) at each site during each event and over time (Table 33). For more information on transect agreements for replicate transects and descriptive statistics of stream discharge see Appendix 4.

This study is among the first to use Doppler technology to quantify flow within the shallow tidal streams along the Texas Gulf coast. Presently, there is no accepted methodology for analyzing and reporting flow data under such conditions, except to take upwards of eight transects per site per event or to report only the values obtained for one transect (Norris 2001). Following the USGS standard protocol of conducting four transects, this study documents variation in stream discharge and velocities over relatively short periods of time in tidal streams. In addition to stream discharge, time-series of current velocity measurements (ADV data) were collected from the middle station in each study stream between June 2003 and November 2004. Although results of analyses for each site are discussed in Appendix 4, a few general patterns regarding stream discharge at these sites are worth noting here.

At all stations, discharge was highly variable as indicated by the standard deviation of the means. Peak flows were recorded in September 2003 at sites along the mid-Texas coast (Table 33).

When the two years are considered separately, peak flows occurred in different months. In addition, the Mid-coast sites in 2004 recorded peak flows during different months for each station (Table 33), though the highest flows probably occurred in May. Stream discharge in May 2004 was recorded only at Garcitas Creek, due to flooding at West Carancahua and Tres Palacios, but this data is not presented in Table 33.

Detecting Bi-directional Flows

Stream discharge measurements were recorded at a total of 9 tidally influenced stations in three coastal streams. Out of all events recorded at these sites between June 2003 and November 2004, none exhibited bi-directional flows.

Table 33. Mean discharge (cfs) at study sites on three tidal streams on the mid-Texas coast. Means were calculated from estimates of volume transport given by replicate transects obtained using an ADCP during each sampling event between April 2003 and November 2004. Mean discharge in each month was determined using all replicate transects with reasonable estimates of discharge. Additional descriptive statistics are provided in Appendix 4Sub Appendix 6B.

Study Stream	**Site Name**	**2003**						**2004**					
		April*	May	June	Aug	Sept**	Nov	March	May**	July	Aug	Sept	Nov
West Carancahua	WC1	107	141	108	158	691	62	98	--	78	140	354	97
	WC2	244	96	26	82	729	149	69	--	29	112	405	59
	WC3	--	557	1,645	1,105	2,965	774	845	--	545	127	274	672
Garcitas	GC1	172	76	142	57	1,345	118	141	--	38	29	355	34
	GC2	186	426	97	138	1,631	336	314	4,696	86	199	813	217
	GC3	218	555	559	102	1,922	251	823	1,826	30	222	274	95
Tres Palacios	TP1	31	182	53	375	3,513	--	184	--	113	213	34	859
	TP2	497	401	41	404	3,605	58	173	--	141	80	244	1,993
	TP3	1,050	1,409	458	345	4,302	639	121	--	918	74	207	2,146

*Replicate measures of mean discharge during most events was not sufficiently consistent (within USGS recommended 5% agreement) to calculate mean discharge with confidence. Values are reported here to provide a general estimate of stream discharge at these sites.
** September 2003 and May 2004 are considered flood events.

Table 34. Mean discharge (cfs ± SE) over time (from April 2003 to November 2004) for each study site on three tidal streams on the Mid-Texas coast. Mean discharge was determined using all replicate transects with reasonable estimates of discharge. Additional descriptive statistics are provided in Appendix 4, Sub-Appendix 6A.

Stream Station	**West Carancahua**	**Garcitas Creek**	**Tres Palacios River**
1	184 ± 27	183 ± 49	625 ± 183
2	186 ± 32	575 ± 150	642 ± 169
3	958 ± 130	692 ± 158	1,085 ± 195

Flow Characteristics of Tidal Streams on the Mid-Texas Coast

Considering the geographic characteristics of these sites, river discharge will be subject to tides, local rainfall, winds, and resonance of bays. Mean discharge over time at the downstream station of each stream was calculated including all sampling periods from May 2003 to November 2004. Mean discharge over time was highest at the Tres Palacios River (1,085 cfs ± 1,262) as compared to West Carancahua Creek (958 cfs ± 812) and Garcitas Creek (692 cfs ± 1,011). Flow was highly variable in these mid-coastal streams. See Table 33 to compare stream discharge at each station during each sampling event, Table 34 for mean discharge at each station for the period April 2003 to November 2004, and Appendix 4.Sub-Appendix 6A for additional descriptive information. Within this data set, simultaneous measures of current velocity were collected at the middle station in all three streams during July 2004. For this date only, flow at these stations is directly comparable.

West Carancahua Creek

West Carancahua Creek – Flow Characteristics

Mean discharge over time at the upstream and middle stations in West Carancahua Creek was low (<190 cfs; Table 33). Though flows were variable, they were relatively low and similar to the upstream and middle stations on the Tres Palacios River and Garcitas Creek (Figs. 11, 12) In November 2003, current velocities were very low, but showed upstream and downstream flows consistent with tidal events. See Appendix 4-Fig. 6D for more details.

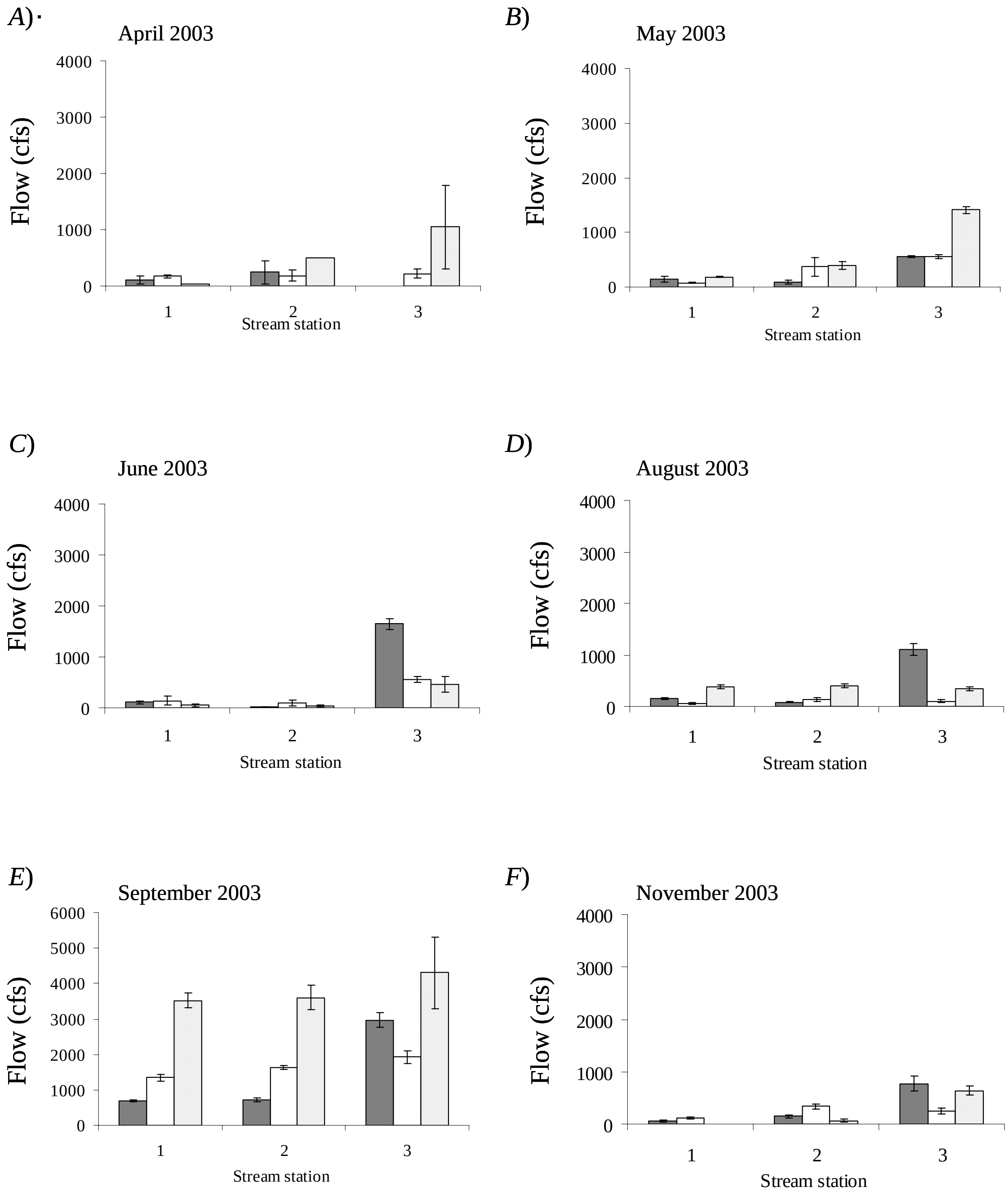


Figure 11. Mean flow (cfs) ± 1 SD at study sites along three tidal streams on the Mid-Texas Coast, West Carancahua Creek (the reference site, dark grey), Garcitas Creek (white), and the Tres Palacios River (light grey), for A) April, B) May, C) June, D) August, E) September, and F) November 2003. Stream stations are: (1) upstream, (2) middle, and (3) downstream.

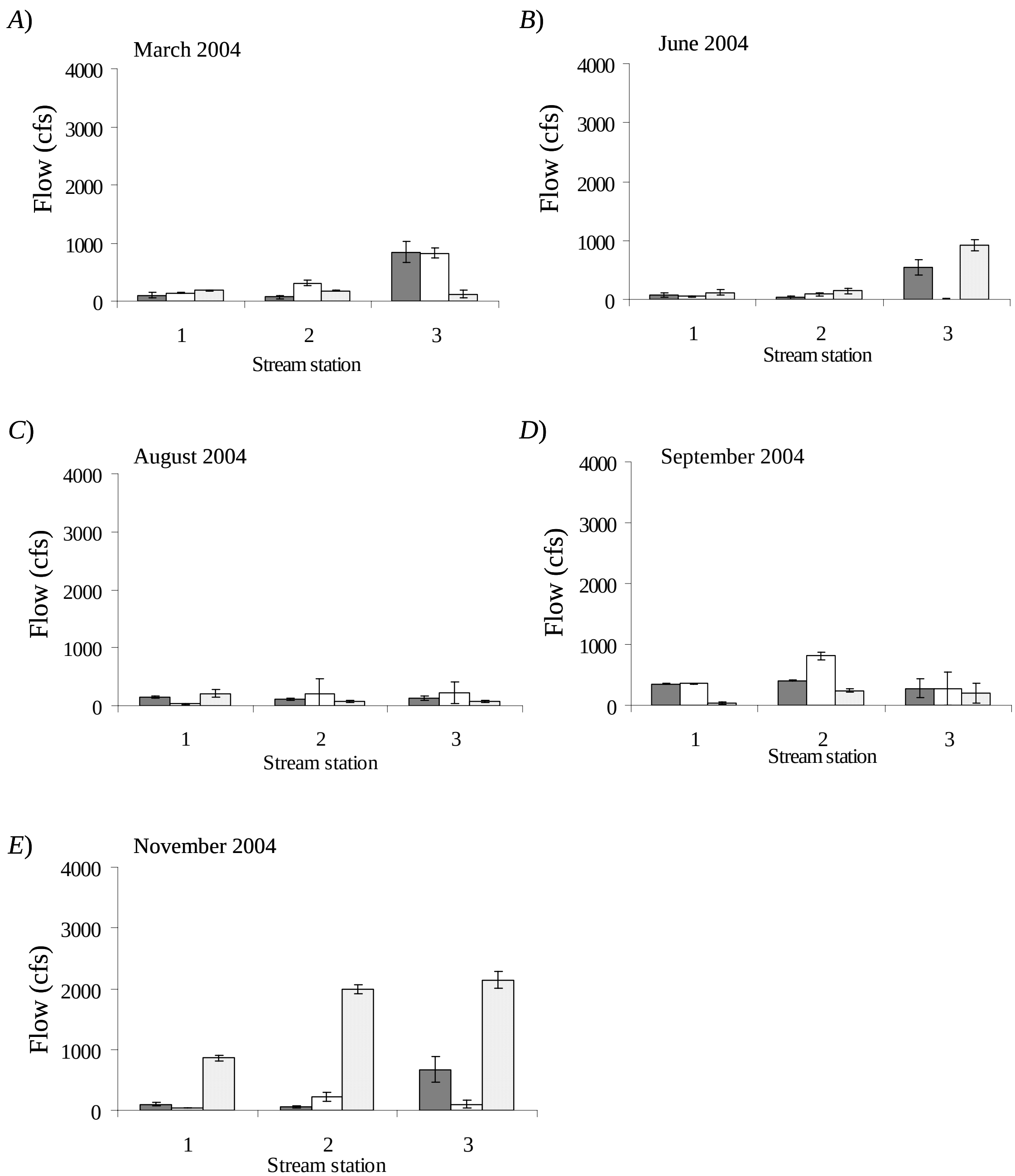


Figure 12. Mean flow (cfs) ± 1 SD at study sites along three tidal streams on the Mid-Texas Coast, West Carancahua Creek (the reference site, dark grey), Garcitas Creek (white), and the Tres Palacios River (light grey), for A) March, B) June, C) August, D) September, and E) November 2004. Stream stations are: (1) upstream, (2) middle, and (3) downstream.

Garcitas Creek

Garcitas Creek – Flow Characteristics

The three downstream stations selected for study represent locations that are most likely to be influenced by tides in each of these streams. When comparing mean discharge over time among the downstream stations, Garcitas Creek had the lowest mean discharge (690 cfs) of the three streams (Table 34; Figs. 11, 12). Current velocities were measured for only one day in June 2003 and August 2003, during which flow was influenced by tidal changes as indicated by the changing direction of vectors (Appendix 4 Figs. 4A and B respectively). In September 2003, flows at Garcitas Creek were downstream and showed no tidal influence (Appendix 4 Fig. 4C). This was due to a recent rainfall event increasing the level of instream flow. During November 2003 and March 2004, measured flows were low and influenced by tidal cycles (Appendix 4 Figs. 4D, 5A. Measurements taken in May 2004 are erratic, but show a curious abrupt change in flow around noon on May 13 (Appendix 4 Fig. 5B). At this time, flows were strongly downstream for several hours. Data from the Tres Palacios airport show a strong cold front arrived on May 13 with North-North East winds from 18 to 36 miles per hour which would account for the abrupt change in flow (Appendix 5). Flow measurements recorded over two days in July 2004 indicated some tidal influence with flows directed upstream between intervals of downstream flow (Appendix 4 Figs. 5C, 11). These results are similar to those found at the middle Tres Palacios station and West Carancahua Creek during this same time period. Current velocity was fairly strong during the sampling period in August 2004 with distinct upstream and downstream periods of flow (Appendix 4 Fig. 6A) that appear to be strongly influenced by tidal currents (Appendix 4 Fig. 12B). A similar pattern of flow occurs again in September 2004.

Garcitas Creek – Tidal Influence on Stream Discharge

Generally, current velocities were weak, and tidal currents were stronger than residual currents, thus influencing the direction of flow in Garcitas Creek.

Tres Palacios River

Tres Palacios River – Flow Characteristics

Mean discharge over time (from May 2003 to November 2004) at the downstream station on the Tres Palacios River was the highest of all three mid-coastal study streams (Table 34). While mean discharge over time at the upper and middle stations on the Tres Palacios was only 60% of that at the downstream station, these estimates for the Tres Palacios River, as well as for other mid-coast study streams, were influenced by the high values measured in

September 2003. At all stations on the Tres Palacios River, mean discharge in September 2003 was two to six times higher than in any other month. When the estimate of mean discharge over time excludes such extreme events, the upstream-downstream pattern of discharge remains the same, though the values are much lower (ranging 250 cfs to 745 cfs, rather than the reported mean values of 625 cfs to 1,100 cfs, Table 34).

Though a detailed comparison of velocity measurements at the middle station was difficult to conduct with this data, two features are readily apparent. First, flow in the Tres Palacios River had much higher velocities than in West Carancahua Creek. Second, the strength of the tidal signal indicated by the direction of currents is stronger in the Tres Palacios River. In September 2003, flow was uniformly downstream and very strong. Current velocities in November 2003 and March 2004 were relatively weak, but exhibited flow patterns indicative of tidal influences. Again, in May 2004 stream flow was consistently downstream during the 24 hour sampling period.

In July 2004, current velocities in all mid-coastal study streams were measured during the same 48-hour period which allowed for comparison of flows among streams. Flows in the Tres Palacios and in Garcitas Creek were similar in magnitude with a similar pattern of switching between phases of upstream and downstream flow (Appendix 4 Fig. 12C and Fig. 9C, respectively). West Carancahua Creek, however, had lower current velocities and the tidal signal is not as distinct (Appendix 4 Fig. 7C). Flows measured in August and September 2004 at the middle station on the Tres Palacios indicate a fairly strong current with directional changes over the 24 hour period (Appendix 4 Fig. 13A, B). November 2004 flows were much weaker but still exhibited signs of tidal influence (Appendix 4 Fig. 13C).

Water Quality

Physiochemical Profiles – Tres Palacios and Carancahua Creeks

Field parameter surface measurements taken at Tres Palacios River and Carancahua Creek are summarized in Table 35. The vegetation-based landscape approach used to select the fixed sampling stations; one characteristic of the upper tidal reach, one characteristic of the middle, and one characteristic of the lower tidal reach; was quite successful in identifying a general salinity gradient present within each study stream. Upper stations on both Tres Palacios and Carancahua Creek were nearly fresh (salinity < 1 PSU), although salinity ranged from a low of 0.1 PSU to a high of 4.4 PSU. Evidence of elevated surface salinity levels, in the form of marine acorn barnacle (Balanomorpha) calcareous plates on tree limbs and other hard structures within the stream, was routinely encountered at these uppermost stations. Secchi depths were highest in the upper tidal reaches, with increased turbidity and lower water clarity found at the lower stations. While temperature, dissolved oxygen, and pH were quite similar between the upper stations on both streams, surface dissolved oxygen was more variable within Carancahua Creek, ranging from 2.9 – 9.3 mg/L.

Mid-depth field parameters measurements revealed the presence of vertical stratification of the water column at both Tres Palacios and Carancahua Creeks (Table 36). While mean water temperature and pH decreased and mean salinity increased with depth, dissolved oxygen showed the most substantial change when compared to the surface values. This stratification was especially evident at the upper tidal station on Carancahua Creek (WC 1), where mid-depth dissolved oxygen values averaged < 3 mg/L. On both streams, the upper and middle stations had average dissolved oxygen percent saturation values < 70%.

The presence of vertical stratification was reinforced by the bottom-water field parameter measurements at Tres Palacios and Carancahua Creeks (Table 37). While temperature and pH again decreased with depth and salinity increased with depth (salinities were generally higher in Tres Palacios), average dissolved oxygen values at the upper and middle stations on both streams was < 4 mg/L. Hypoxic conditions were prevalent in the bottom-water dissolved oxygen concentrations on the upper and middle stations on Carancahua Creek (percent saturation values ranged from 0.25 – 71.3%). Vertical stratification was less evident on the lower tidal reaches in both streams, and low dissolved oxygen concentrations were not encountered at these lowest stations (see Table 37).

Ordination of the stations by cluster analysis of surface field parameter measurements defined four main station groups (Fig. 13). The upper and middle stations of both Tres Palacios and Carancahua Creeks were well mixed within the largest two groups identified from the cluster analysis (groups 1 and 2, see Fig. 14a). At a similarity level of 3.5, these four groups were internally consistent with respect to the seasonality of the surface water quality profile collections (Fig. 14b). Principal components analysis of the surface field parameter measurements revealed that the first two components explained 68.0% of the variability (Table 38), and the dimensionless x and y axis of the MDS configurations presented in Figures 15a and 15b are reflective of the first two principal components. The first component corresponds to inflow, with all five environmental parameters negatively loaded on the first component and pH measurements best separating the station groupings along the x-axis in Fig.15a. These samples corresponded to the lowest salinity conditions, often recorded when streamflow velocities were at their maximum during flooding conditions. Salinity, dissolved oxygen, and Secchi depth all had approximately the same magnitude of negative loading on the first principal component (salinity increasing from left to right along the x-axis, see Fig.15b). The second principal component corresponds to the y-axis shown in Figures 14a and 14b, and best

Table 35. Surface-water field parameters by station for Tres Palacios River and Carancahua Creek. Specific conductance (Sp. Cond) in µmhos/cm, salinity in PSU. Data are means (n=12, unless otherwise noted). Standard deviations are presented in parentheses.

	Temp (^oC)	pH	D.O. mg/L	D.O. %Sat	Sp. Cond	Salinity	Secchi (m)
TP 1	26.59 (4.8)	7.61 (0.4)	6.26 (1.5)	77.43 (20.7)	1696.08 (2428.8)	0.90 (1.3)	0.28 (0.2)
TP 2	27.20 (4.8)	7.75 (0.4)	6.48 (1.3)	82.28 (19.4)	2198.25 (2699.3)	1.18 (1.5)	0.27 (0.2)
TP 3 [a]	26.52 (3.5)	8.07 (0.4)	6.72 (1.4)	86.64 (20.0)	9445.27 (8349.7)	5.51 (5.0)	0.19 (0.1)
WC 1 [b]	26.79 (5.2)	7.48 (0.6)	5.50 (1.9)	68.00 (25.3)	1824.09 (2525.8)	0.97 (1.4)	0.24 (0.1)
WC 2 [b]	27.46 (4.9)	7.63 (0.6)	6.02 (1.5)	76.36 (17.8)	2217.18 (3007.4)	1.19 (1.7)	0.24 (0.1)
WC 3 [b]	26.50 (5.9)	7.95 (0.7)	7.36 (1.7)	92.49 (20.5)	4901.27 (5405.2)	2.75 (3.1)	0.19 (0.1)

[a] n=11, TP 3 Surface Profile missing from July 2004.
[b] n=11, No Water Column Profiles taken during the May 2004 flooding event at WC 1, WC 2, or WC 3.

Table 36. Mid-depth field parameters by station for Tres Palacios River and Carancahua Creek. Specific conductance (Sp. Cond) in µmhos/cm, salinity in PSU. Data are means (n=12, unless otherwise noted). Standard deviations are presented in parentheses.

	Temp (^oC)	pH	D.O. mg/L	D.O. %Sat	Sp. Cond	Salinity
TP 1	25.67 (4.5)	7.40 (0.3)	4.69 (1.6)	57.38 (18.0)	1895.67 (2681.8)	1.02 (1.5)
TP 2	26.11 (4.8)	7.55 (0.3)	4.95 (1.2)	60.99 (12.2)	2703.58 (3361.5)	1.49 (1.9)
TP 3 [a]	26.40 (4.6)	7.59 (0.3)	5.54 (1.3)	69.60 (21.6)	217.67 (168.5)	0.11 (0.1)
WC 1 [b]	25.39 (5.1)	7.22 (0.5)	2.95 (1.7)	35.86 (20.3)	2108.55 (2848.2)	1.13 (1.6)
WC 2 [b]	26.08 (4.8)	7.46 (0.6)	4.74 (1.6)	57.97 (18.6)	2364.82 (3088.6)	1.28 (1.7)
WC 3 [c]	27.21 (4.1)	7.78 (0.7)	6.82 (1.8)	86.98 (20.8)	4993.90 (5713.3)	2.83 (3.3)

[a] n=3, TP 3 Mid Depth Profile not normally recorded due to shallow water depth at this station.
[b] n=11, No Water Column Profiles taken during the May 2004 flooding event at WC 1, WC 2, or WC 3
[c] n=10, WC 3 Mid Depth Profile not recorded during April 2003 sampling trip due to shallow conditions at this station.

Table 37. Bottom-water field parameters by station for Tres Palacios River and Carancahua Creek. Specific conductance (Sp. Cond) in µmhos/cm, salinity in PSU. Data are means (n=12, unless otherwise noted). Standard deviations are presented in parentheses.

	Temp (^{o}C)	pH	D.O. mg/L	D.O. %Sat	Sp. Cond	Salinity
TP 1 [a]	25.78 (4.6)	7.36 (0.3)	3.67 (1.9)	44.21 (22.2)	3120.09 (4869.7)	1.74 (2.8)
TP 2 [a]	25.91 (4.8)	7.44 (0.2)	3.21 (1.7)	38.82 (18.4)	4564.18 (5685.0)	2.57 (3.3)
TP 3 [b]	26.89 (3.7)	8.12 (0.4)	6.17 (1.0)	80.68 (15.3)	11089.80 (9220.3)	6.12 (5.0)
WC 1 [c]	24.73 (4.4)	7.04 (0.3)	1.50 (1.8)	17.54 (21.3)	3235.64 (4271.3)	1.79 (2.4)
WC 2 [c]	25.48 (4.2)	7.21 (0.4)	2.78 (1.4)	33.46 (15.7)	3285.73 (3720.9)	1.77 (2.1)
WC 3 [c]	25.64 (5.4)	7.76 (0.7)	6.46 (1.7)	79.24 (18.2)	5263.27 (5499.2)	2.97 (3.2)

[a] n=11, Bottom Profiles at TP 1 and TP 2 not collected during the May 2004 flooding event.
[b] n=5, Bottom Profiles not normally recorded at TP 3 due to shallow conditions at this station
[c] n=11, No Water Column Profiles taken during the May 2004 flooding event at WC 1, WC 2, or WC 3.

Table 38. Correlations of the field parameter surface measurements – temperature (^{o}C), salinity (in PSU), and Secchi depth (m) – with the first 3 principal components, percent variation (cumulative percentage) for each principal component, and eigenvalues for Tres Palacios River and Carancahua Creek.

Principal Component	Cumulative Percent	Eigenvalue	Temp	pH	DO mg/L	Salinity	Secchi
PC1	46.1	2.31	-0.184	-0.618	-0.449	-0.434	-0.441
PC2	68.0	1.09	0.828	0.043	0.344	0.279	0.340
PC3	84.7	0.83	0.253	0.135	0.657	0.569	0.403

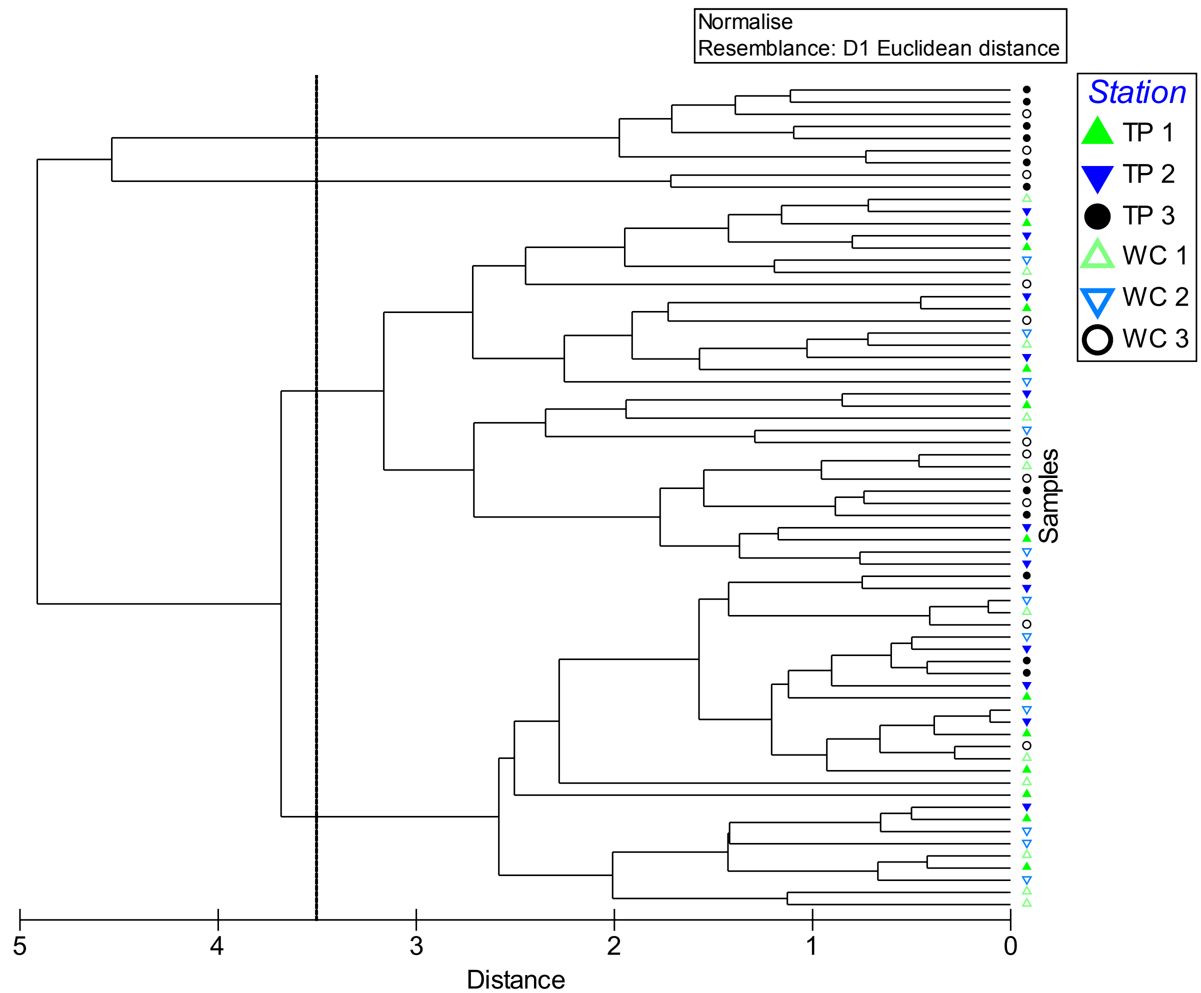


Figure 13. Cluster dendrogram showing the similarities (as measured by normalized Euclidean distance) between stations based on surface measurements of field parameters taken from Tres Palacios River and Carancahua Creek. Stations with distance levels < 3.5 are joined as similar groups.

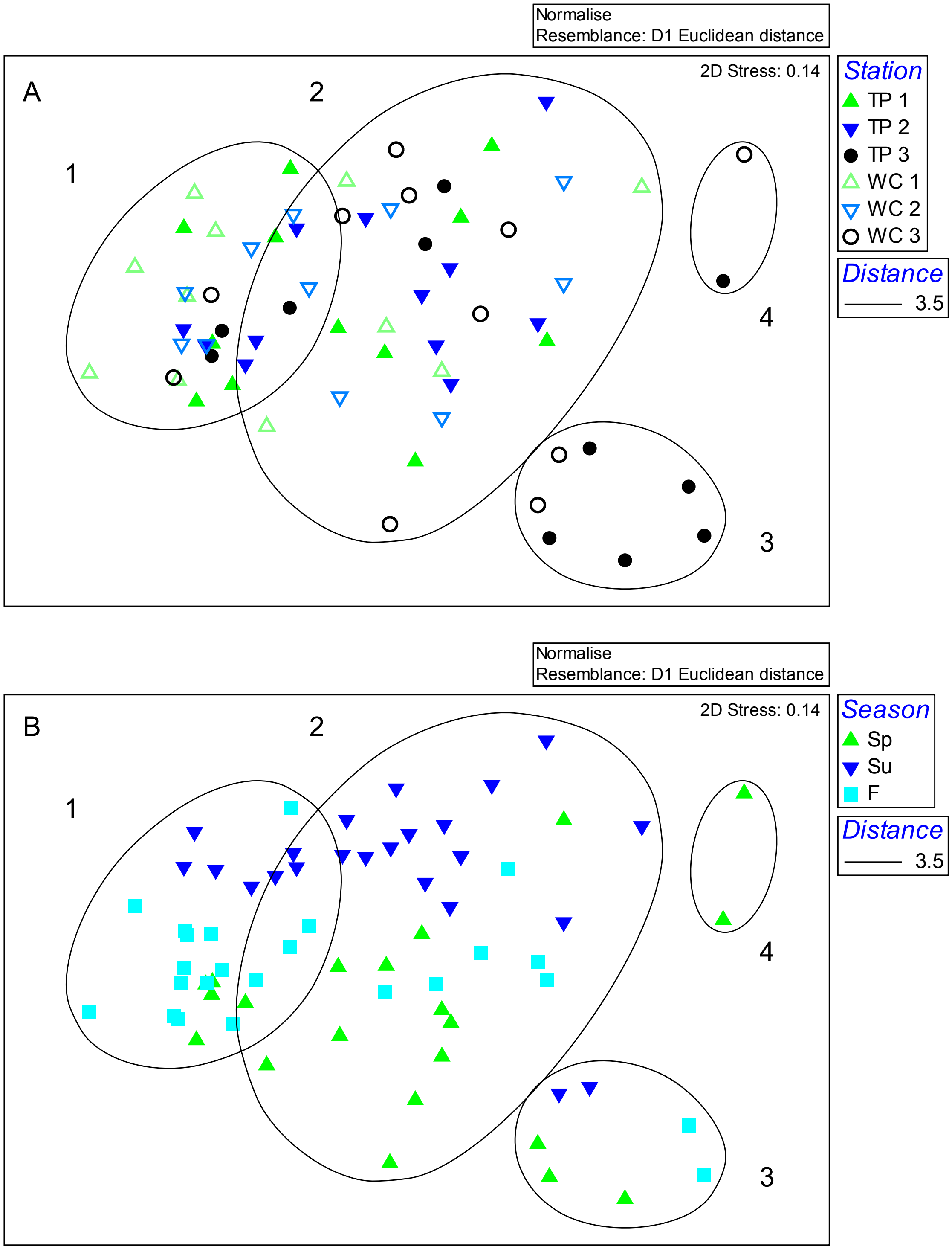
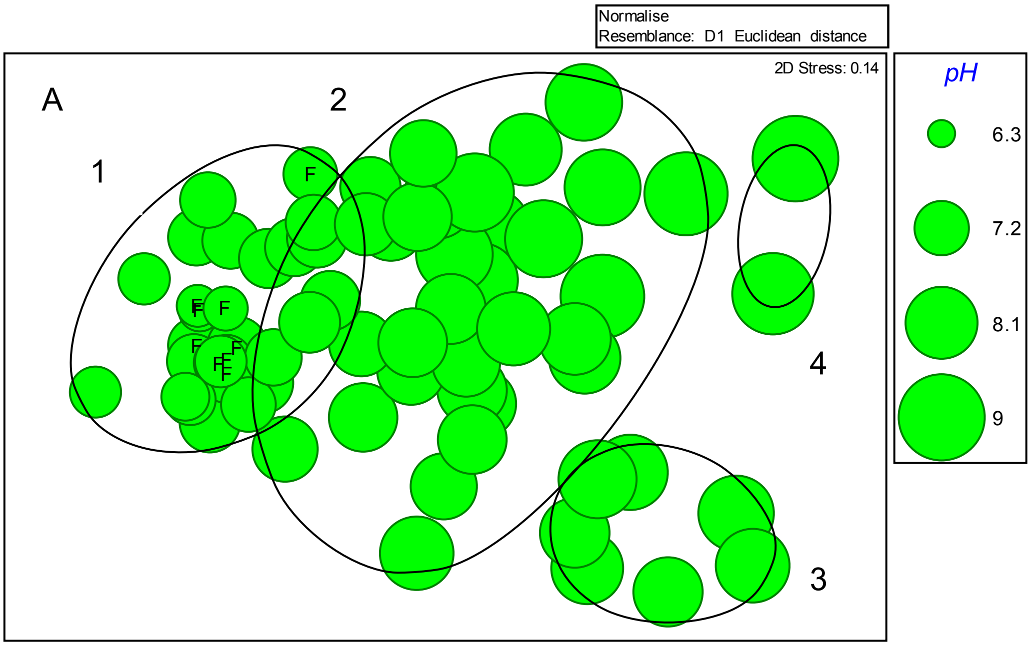


Figure 14. Multidimensional scaling ordination of the stations based on surface measurements of field parameters taken from Tres Palacios River and Carancahua Creek. A = Station groups identified from the cluster analysis (Fig. 13), B = Identical configuration as A, but identifying season of collection.



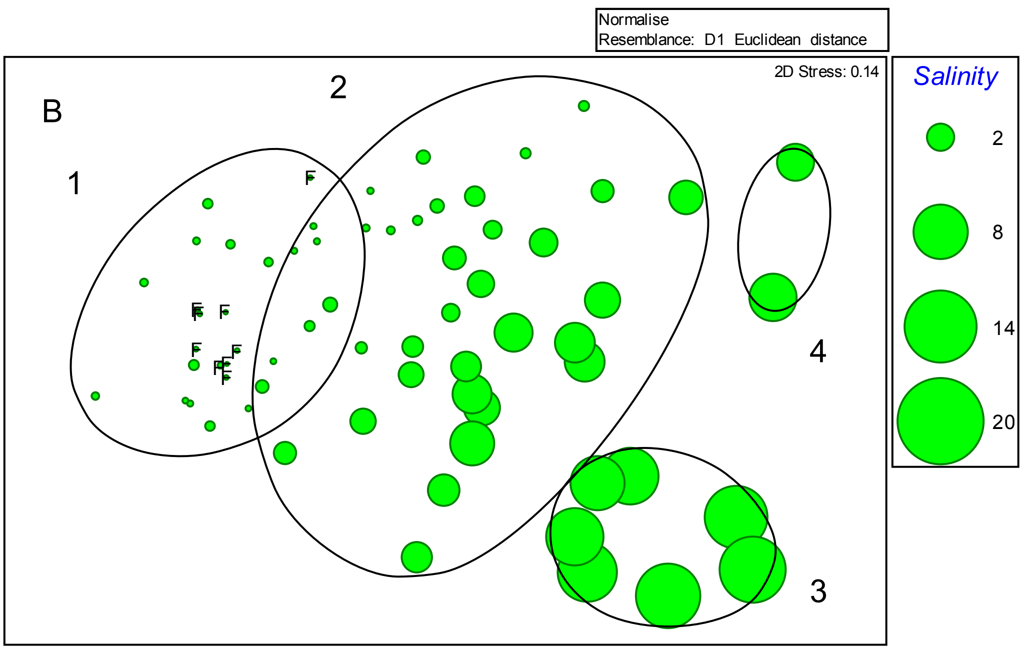


Figure 15. Multidimensional scaling ordination of the stations based on surface measurements of field parameters taken from Tres Palacios River and Carancahua Creek. Station configuration based on Fig. 14a, but overlaid onto each station are: A = pH measurements, and B = salinity measurements. Size of each circle is represented by the scale for each Figure. Flooding condition sampling events are designated by F in each Figure.

depicts seasonality (temperature loading on component two = 0.828, see Table 35), separating the summer sampling events and the corresponding warmer surface water temperatures found at all stations from the other sampling seasons.

Based on 1,000 permutations of the sample labels that make up the matrices of field parameter collections, Spearman's rank correlations between the surface and mid-depth measurements was $\rho_S = 0.562$ (*prob*. = 0.001) for Tres Palacios, and $\rho_S = 0.769$ (*prob*. = 0.001) for Carancahua Creek. Rank correlations between the surface and bottom-water measurements were $\rho_S = 0.503$ (*prob*. = 0.001) for Tres Palacios, and $\rho_S = 0.519$ (*prob*. = 0.001) for Carancahua Creek. Mid-depth collections were much more correlated to bottom-water collections, with rank correlation of $\rho_S = 0.824$ (*prob*. = 0.001) for Tres Palacios, and $\rho_S = 0.773$ (*prob*. = 0.001) for Carancahua Creek. While these correlations confirm the presence of vertical stratification within both tidal stream systems (surface and mid-depth physiochemical measurements are more correlated than are surface and bottom-water measurements), this stratification is not extreme and it is driven primarily by differences in inflow (pH, salinity, and Secchi depth were all negatively loaded on component one and were approximately of similar magnitude) and temperature (seasonality).

Analysis of Similarity (ANOSIM) tests of the surface physiochemical profiles within Tres Palacios showed that the lower station was significantly different from the mid and upper stations (Global R = 0.132, $p = 0.021$), and the mid and upper stations were themselves similar in terms of their instantaneous water quality measurements (Fig. 16). While the lower-most station on Carancahua Creek appears to follow the pattern seen with Tres Palacios (separating off from the others), ANOSIM results for Carancahua Creek showed that all stations were similar in their surface water column properties (Global R = 0.049, $p = 0.126$). In both creeks, the upper and middle stations were very similar in their water column properties. The same result is found using either the mid-depth or the bottom-water profiles, reinforcing the results of the rank correlation tests. The middle and upper stations are quite similar, and the lower-most station is responsible for any differences seen.

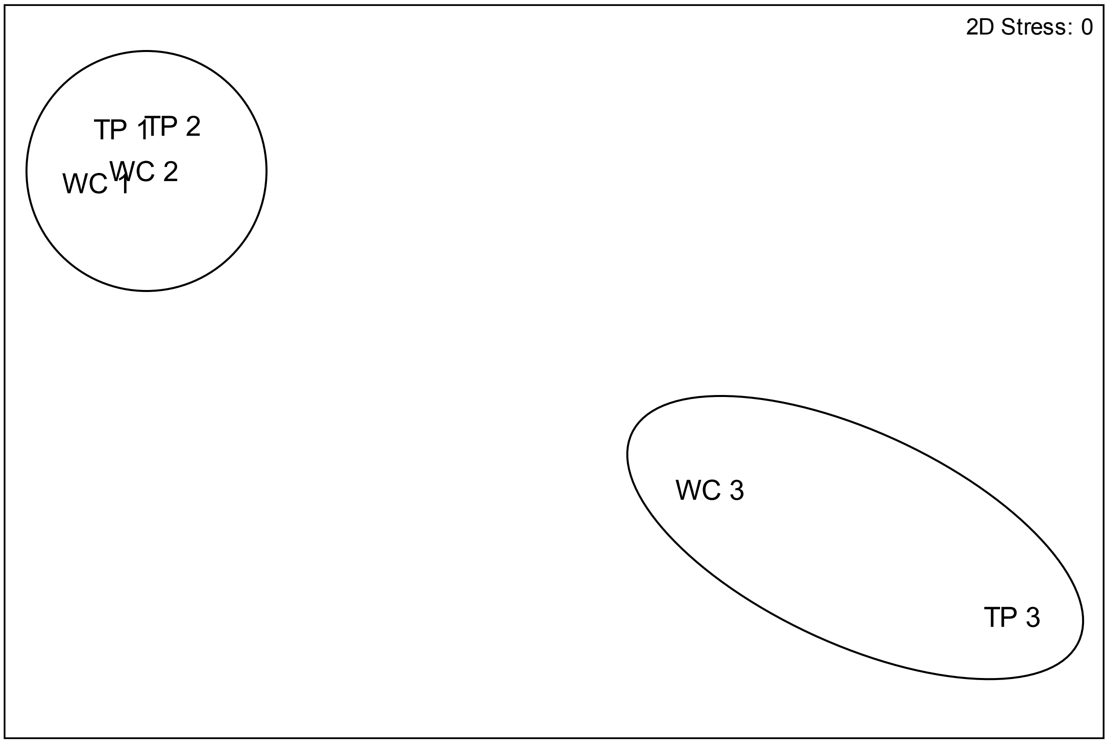


Figure 16. Means plot MDS ordination of the stations based on surface measurements of field parameters taken from Tres Palacios River and Carancahua Creek. Stations within an ellipse are not significantly different based on ANOSIM comparisons among the study streams ($p > 0.05$).

Physiochemical Profiles – Garcitas and Carancahua Creeks

Field parameter surface measurements taken at Garcitas and Carancahua Creeks are summarized in Table 39. As was the case with the other study streams, the vegetation-based landscape approach used to select the fixed sampling stations was successful in identifying the salinity gradient present. The upper-most station on Garcitas Creek was not as fresh as the upper station on Carancahua Creek (mean salinity > 1.5 PSU at GC 1, see Table 39), and the salinity gradient over the length of Garcitas Creek was not as extreme as that found on Tres Palacios. Salinities at the upper station also ranged from very fresh to brackish (from a low of 0.05 PSU to a high of 7.9 PSU), and acorn barnacle plates were very numerous on most hard structures in contact with the surface waters. Of all the fixed sampling stations, Secchi depths were the greatest in each tidal reach of Garcitas Creek, averaging more than 0.3 m at each fixed sampling station.

While mid-depth field parameter measurements revealed the presence of vertical stratification within Carancahua Creek (Table 40), Garcitas Creek generally lacked any substantial differences between surface and mid-depth measurements. Dissolved oxygen values measured within the surface layer compared to the mid-depth layer of each station were approximately within 1 mg/L of one another, with the mid-depth measurement being consistently lower. Salinity values were not markedly different between the surface and mid-depth values (Tables 39 and 40).

Bottom-water field parameter measurements at Garcitas Creek were characterized by generally increasing bottom salinities down the entire tidal reach, and the highest bottom-water dissolved oxygen values found on any of the upper or middle stations (Table 41). Interestingly, bottom-water dissolved oxygen values at the most downstream station on Garcitas Creek were, on average, the lowest values encountered of all the most downstream stations on the mid-coast. This could be in response to the depth of this station relative to the other lower-most fixed locations, as the depth at GC 3 averaged 3 m, while TP 3 was rarely over a meter (hence the elimination of the mid-depth sample on most collecting trips) and WC 3 averaging approximately 1.6 meters. Salinities were higher overall in Garcitas Creek, and temperature and pH again decreased with depth and salinity increased with depth. Although not reflected in average values reported in Table 41, hypoxic conditions prevalent for bottom-water dissolved oxygen concentrations at upper and middle stations on Carancahua Creek were also seen in Garcitas Creek (bottom-water dissolved oxygen values ranged from a low of 0.82 to a high of 8.3 mg/L). Vertical stratification was far less evident within the tidal reaches of Garcitas Creek.

Surface field parameter based ordination by cluster analysis defined three main station groups (Fig. 17). The upper, middle, and lower stations of both tidal streams were represented in each of the station groups (see Fig. 18a). At a

Table 39. Surface-water field parameters by station for Garcitas and Carancahua Creeks. Specific Conductance (Sp. Cond) in µmhos/cm, salinity in PSU. Data are means (n=12, unless otherwise noted). Standard deviations are presented in parentheses.

	Temp (^{o}C)	pH	D.O. mg/L	D.O. % Sat	Sp Cond	Salinity	Secchi (m)
GC 1	25.93 (5.1)	7.36 (0.6)	5.82 (1.2)	71.34 (10.1)	2822.75 (4430.0)	1.57 (2.5)	0.32 (0.2)
GC 2	26.08 (5.1)	7.48 (0.7)	6.33 (1.4)	79.22 (18.4)	4471.00 (6478.7)	2.56 (3.8)	0.32 (0.2)
GC 3	26.04 (4.8)	7.50 (0.6)	6.44 (1.2)	80.68 (12.2)	6527.75 (7971.2)	3.78 (4.8)	0.31 (0.2)
WC 1 [a]	26.79 (5.2)	7.48 (0.6)	5.50 (1.9)	68.00 (25.3)	1824.09 (2525.8)	0.97 (1.4)	0.24 (0.1)
WC 2 [a]	27.46 (4.9)	7.63 (0.6)	6.02 (1.5)	76.36 (17.8)	2217.18 (3007.4)	1.19 (1.7)	0.24 (0.1)
WC 3 [a]	26.50 (5.9)	7.95 (0.7)	7.36 (1.7)	92.49 (20.5)	4901.27 (5405.2)	2.75 (3.1)	0.19 (0.1)

[a] n=11, No Water Column Profiles taken during the May 2004 flooding event at WC 1, WC 2, or WC 3.

Table 40. Mid depth field parameters by station for Garcitas and Carancahua Creeks. Specific Conductance (Sp. Cond) in µmhos/cm, salinity in PSU. Data are means (n=12, unless otherwise noted). Standard deviations are presented in parentheses.

	Temp (^{o}C)	pH	D.O. mg/L	D.O. % Sat	Sp Cond	Salinity
GC 1 [a]	26.03 (4.5)	7.25 (0.7)	4.88 (1.5)	56.39 (21.4)	2952.27 (4885.6)	1.67 (2.8)
GC 2	25.79 (4.7)	7.36 (0.6)	5.19 (1.8)	63.67 (19.2)	4965.17 (7121.1)	2.87 (4.2)
GC 3	25.69 (4.5)	7.42 (0.5)	5.38 (1.3)	67.12 (15.2)	7796.33 (8531.8)	4.53 (5.1)
WC 1 [b]	25.39 (5.1)	7.22 (0.5)	2.95 (1.7)	35.86 (20.3)	2108.55 (2848.2)	1.13 (1.6)
WC 2 [b]	26.08 (4.8)	7.46 (0.6)	4.74 (1.6)	57.97 (18.6)	2364.82 (3088.6)	1.28 (1.7)
WC 3 [b]	27.21 (4.1)	7.78 (0.7)	6.82 (1.8)	86.98 (20.8)	4993.90 (5713.3)	2.83 (3.3)

[a] n=11, GC 1 Mid Depth Profile not recorded during April 2003 sampling trip due to shallow conditions at this station.
[b] n=11, No Water Column Profiles taken during the May 2004 flooding event at WC 1, WC 2, or WC 3.

Table 41. Bottom-water field parameters by station for Garcitas and Carancahua Creeks. Specific Conductance (Sp. Cond) in µmhos/cm, salinity in PSU. Data are means (n=12, unless otherwise noted). Standard deviations are presented in parentheses.

	Temp (^{o}C)	pH	D.O. mg/L	D.O. % Sat	Sp Cond	Salinity
GC 1	25.41 (4.8)	7.28 (0.6)	4.78 (2.1)	55.93 (21.2)	3205.42 (4920.3)	1.79 (2.8)
GC 2	25.50 (4.6)	7.29 (0.6)	4.08 (1.9)	49.63 (21.2)	6074.25 (7341.9)	3.51 (4.3)
GC 3	25.39 (4.3)	7.44 (0.5)	4.63 (1.8)	56.98 (19.8)	9617.00 (8626.4)	5.63 (5.2)
WC 1 [a]	24.73 (4.4)	7.04 (0.3)	1.50 (1.8)	17.54 (21.3)	3235.64 (4271.3)	1.79 (2.4)
WC 2 [a]	25.48 (4.2)	7.21 (0.4)	2.78 (1.4)	33.46 (15.7)	3285.73 (3720.9)	1.77 (2.1)
WC 3 [a]	25.64 (5.4)	7.76 (0.7)	6.46 (1.7)	79.24 (18.2)	5263.27 (5499.2)	2.97 (3.2)

[a] n=11, No Water Column Profiles taken during the May 2004 flooding event at WC 1, WC 2, or WC 3.

Table 42. Correlations of the field parameter surface measurements – temperature (^{o}C), salinity (in PSU), and Secchi depth (m) – with the first 3 principal components, percent variation (cumulative percentage) for each principal component, and eigenvalues for Garcitas and Carancahua Creeks.

Principal Component	Cumulative Percent	Eigenvalue	Temp	pH	DO mg/L	Salinity	Secchi
PC1	48.9	2.44	-0.253	-0.554	-0.145	-0.536	-0.566
PC2	74.7	1.29	0.572	-0.240	-0.762	-0.012	0.186
PC3	90.2	0.78	0.716	0.199	0.438	-0.472	-0.180

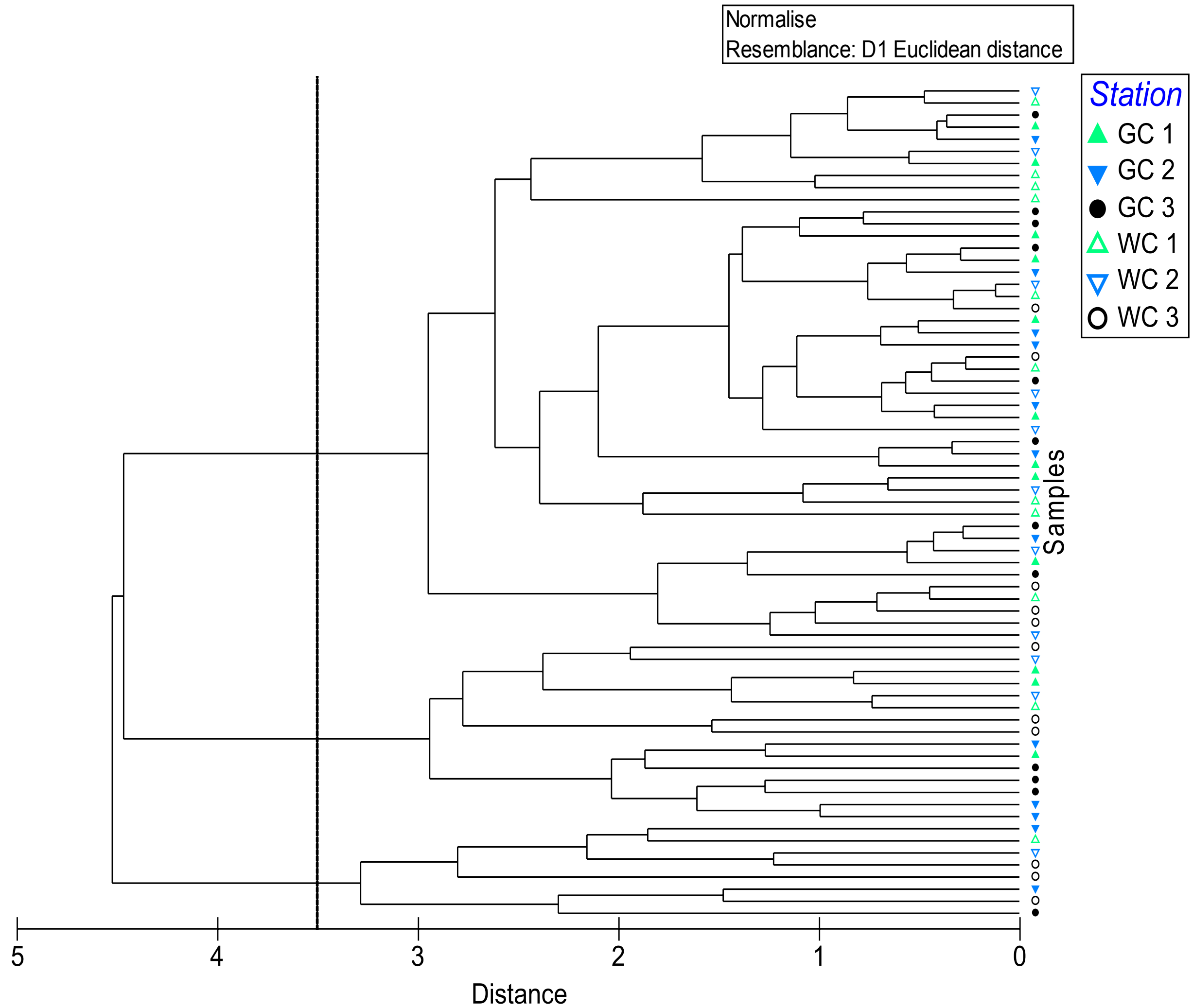


Figure 17. Cluster dendrogram showing the similarities (as measured by normalized Euclidean distance) between stations based on surface measurements of field parameters taken from Garcitas and Carancahua Creeks. Stations with distance levels < 3.5 are joined as similar groups.

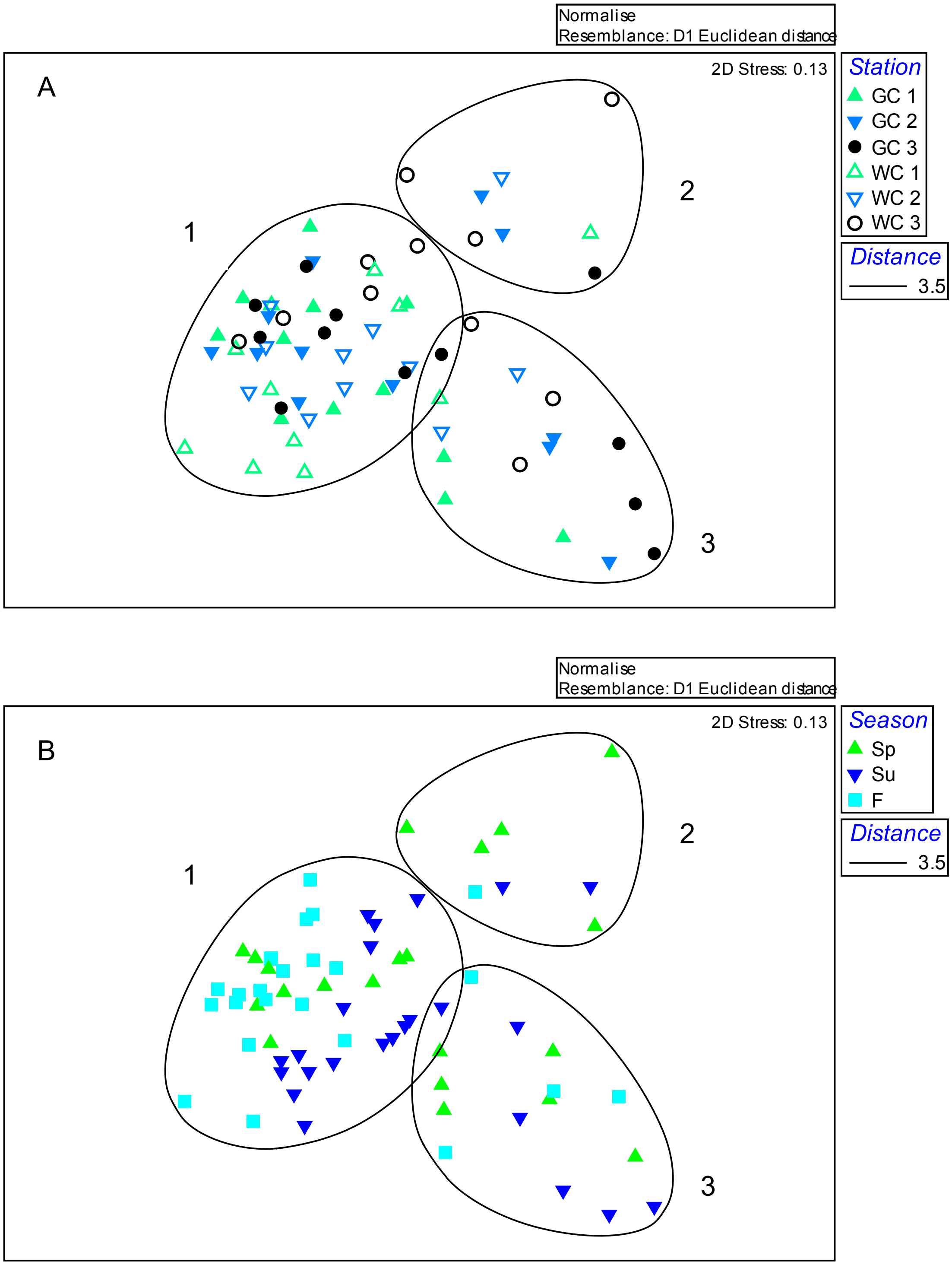


Figure 18. Multidimensional scaling ordination of the stations based on surface measurements of field parameters taken from Garcitas and Carancahua Creeks. A = Station groups identified from the cluster analysis (Fig. 17), B = Identical configuration as A, but identifying season of collection.

similarity distance of 3.5, these three groups did not reveal any large degree of seasonality for the surface water profile collections (Fig. 18b). Spring, summer, and fall season collections are represented within each major group. Principal components analysis of the surface field parameter measurements revealed that the first two components explained 74.7 % of the variability (Table 42) and the MDS configurations presented in Figures 19a and 19b are reflective of the first two principal components identified with this analysis. Again, all five environmental parameters were negatively loaded on the first component, with Secchi depth, pH, and salinity measurements best separating the station groupings along the x-axis in Fig.19a. Samples on the left side of the MDS plot corresponded to the lowest salinity conditions, often recorded during higher streamflow or flood conditions. High loadings on the second component (the y-axis in Figs. 19) included a negative relationship with dissolved oxygen (DO mg/L = -0.762) and a positive relationship with temperature (Temp = 0.572). Salinity and dissolved oxygen, taken in combination, help to explain the station grouping identified from the cluster analysis (Figs. 19). Group 1 consisted of a mixture of all the stations on both creeks, taken primarily during the lowest salinity conditions (including each of the flood samples). Group 2 were higher salinity conditions, but each of these samples had much higher than average dissolved oxygen in the surface waters. Group 3 consisted of the highest salinity conditions, coupled with lower than average dissolved oxygen values.

Rank correlations (based on 1,000 permutations of the sample labels in each comparison) between the surface and mid-depth measurements was $\rho_S = 0.903$ (*prob*. = 0.001) for Garcitas, and $\rho_S = 0.769$ (*prob*. = 0.001) for Carancahua Creek. Correlations between the surface and bottom-water measurements were $\rho_S = 0.789$ (*prob*. = 0.001) for Garcitas, and $\rho_S = 0.519$ (*prob*. = 0.001) for Carancahua Creek. Mid-depth collections were highly correlated to bottom-water collections, with rank correlation of $\rho_S = 0.865$ (*prob*. = 0.001) for Garcitas, and $\rho_S = 0.773$ (*prob*. = 0.001) for Carancahua Creek. More vertical stratification was evident within Carancahua Creek than was seen in Garcitas Creek, and this reinforces the general lack of stratification within Garcitas as seen in Tables 39–41.

Analysis of Similarity (ANOSIM) tests of the surface physiochemical profiles within Garcitas Creek showed that there was no significant difference among the stations (Global R = -0.04, $p = 0.877$, see Fig. 20). This result agrees with the cluster analysis grouping of Fig. 18a, in that each major group of stations consists of a mixture of upper, middle, and lower stations within each study stream. While these groupings of stations can be explained primarily by differences in salinity and dissolved oxygen concentration measurements (Figures 19a and 19b), consistently low or consistently high values of either variable were not found at a particular station on a regular basis. In the MDS configuration of Fig. 20, Garcitas Creek as a whole does appear to be distinct from Carancahua Creek, (each station on Garcitas is more similar to all other stations on Garcitas that to any station on Carancahua), although this degree of

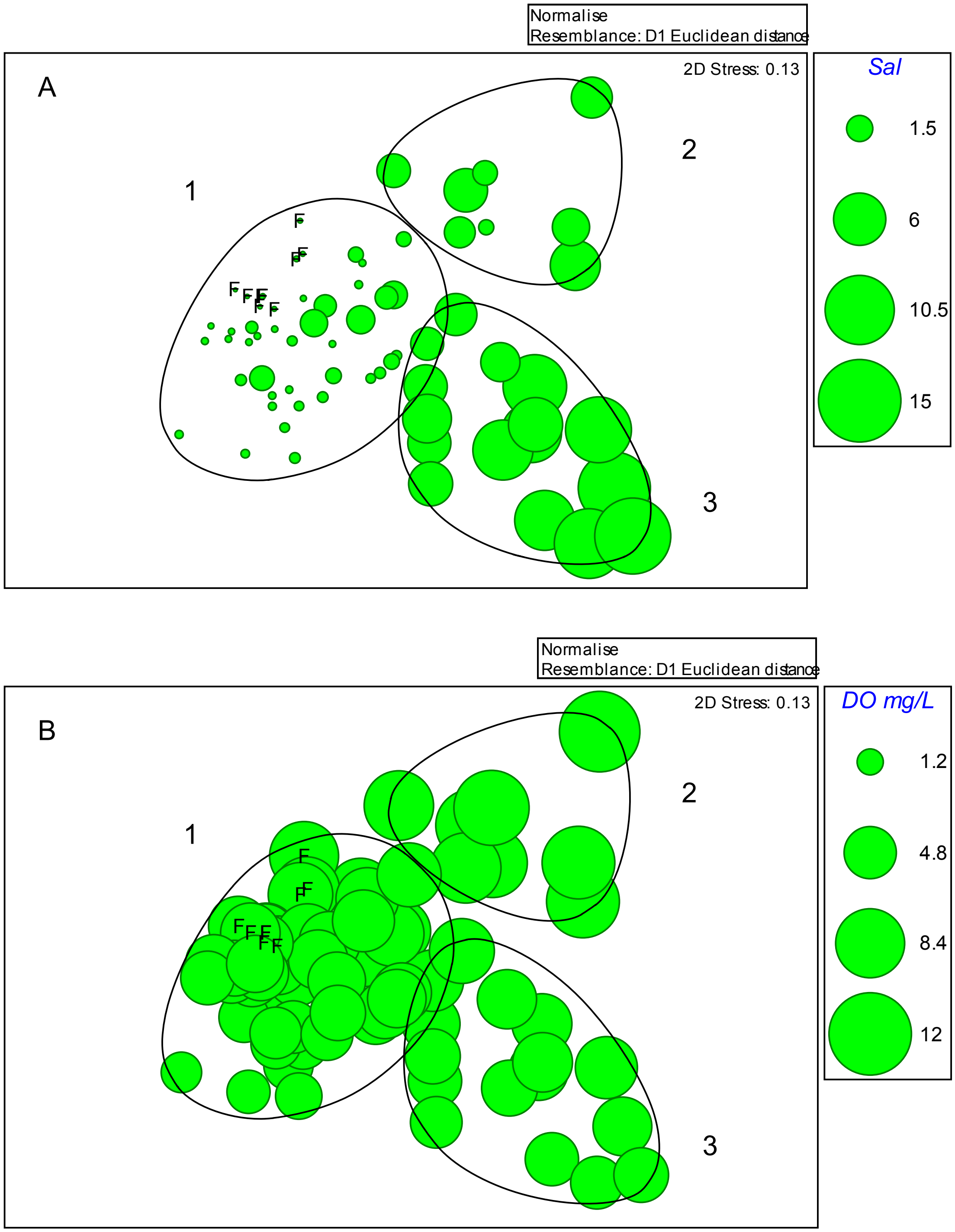


Figure 19. Multidimensional scaling ordination of the stations based on surface measurements of field parameters taken from Garcitas and Carancahua Creeks. Station configurations based on Fig. 18a, but overlaid onto each station are: A = salinity measurements, and B = dissolved oxygen measurements. Size of each circle is represented by the scale for each Figure. Flooding condition sampling events are designated by F in each Figure.

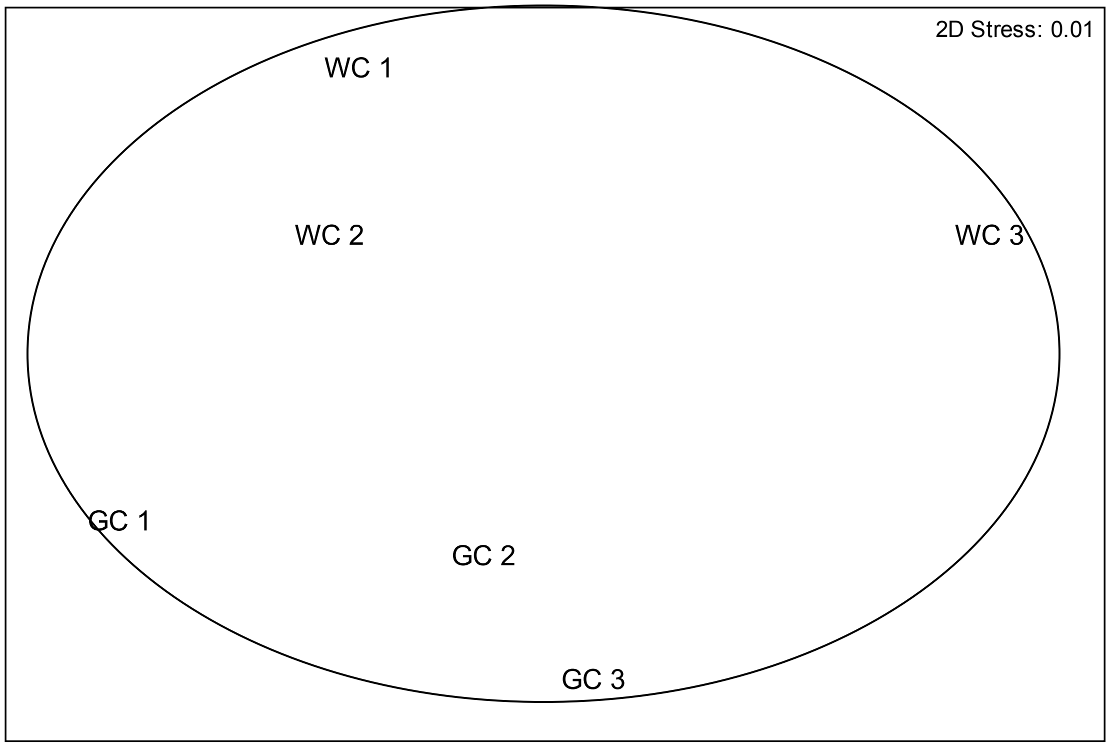


Figure 20. Means plot MDS ordination of the stations based on surface measurements of field parameters taken from Garcitas and Carancahua Creeks. Stations within an ellipse are not significantly different based on ANOSIM comparisons among the study streams ($p > 0.05$).

separation is less than the significance probability level of 0.05.

Short-Term 24-Hour Deployments – Tres Palacios and Carancahua Creek

Due to the numerous challenges encountered during the datasonde deployments (fluctuations in water levels after the sondes were deployed, flooding conditions, equipment malfunctions, and post-calibration failures) only 29 of the 72 total sampling events (40.3%) have complete 24 hour records. Despite this shortcoming, almost every station had at least one successful datasonde deployment in each season. Exceptions were the upper station on Tres Palacios during the fall of both years and the lower station on Carancahua Creek during the spring of both years. A summary of the short-term deployments is presented in Table 43.

The datasondes deployment records were analyzed with a principal components analysis, and those results are shown in Fig. 21. Because two pairs of the variables of interest were nearly perfectly correlated (dissolved oxygen (DO mg/L) and dissolved oxygen percent saturation (DO % Sat) as well as specific conductance (Sp. Cond) and salinity, we dropped one from each of these pairs from the analysis, as the information contained in each of the deleted variables is redundant. Additionally, most of the sondes used in 2003 were not equipped with functioning pH probes, therefore pH was also dropped as a variable of interest in this analysis. The first 2 principal components explained 75.7% of the total variation (Table 44). The seasonality that was identified as an important factor in the analysis of the instantaneous physiochemical profile collections is also an important factor captured by the much longer record collections of the datasondes deployments (compare the separation of summer sampling events in Fig. 23 to Figures 14a and 14b). Stations most negatively correlated with the first principal component tended to be summer collections taken during low salinity and warm water temperatures conditions. These conditions were not unique to either of the study streams, as the mix of stations on the negative side of the x-axis (component 1) were a combination of upper, middle, and lower stations from each stream (see Fig. 23).

ANOSIM of the datasondes deployments revealed that no differences among the stations could be detected (Global R = 0.042, $p = 0.261$, see Fig. 22). This result is not surprising given the amount of variability seen within a station (Table 43), as well as the amount of variability among the stations (Fig. 23). Within each study stream, no differences among the stations were detected (Tres Palacios Global R = 0.09, $p = 0.199$; Carancahua Creek Global R = 0.038, $p = 0.307$) although a significant difference among the seasons was evident within both study streams (Tres Palacios Global R = 0.562, $p = 0.003$; Carancahua Creek Global R = 0.668, $p = 0.001$; see Fig. x). In each comparison, summer collections were the factor responsible for the significant differences seen. These results are in agreements with the results of the principle components analysis as shown in Fig. 21b.

Table 43. Summary statistics of the short-term 24 hour datasondes deployments by station for Tres Palacios River and Carancahua Creek. Specific Conductance (Sp. Cond) in μmhos/cm, salinity in PSU.

	TP 1	**TP 2**	**TP 3**	**WC 1**	**WC 2**	**WC 3**
Min Temp ^{o}C	20.81	17.64	18.98	17.91	17.97	19.06
Max Temp ^{o}C	31.41	32.37	32.94	30.39	31.05	32.82
Avg Temp ^{o}C	27.66	25.66	26.36	24.62	25.71	25.87
Min DO mg/L	3.51	2.79	3.75	0.08	0.50	4.61
Max DO mg/L	6.83	7.79	9.51	7.48	9.80	8.22
Avg DO mg/L	4.82	5.23	6.81	3.58	3.59	6.27
Min DO %Sat	39.90	32.00	43.62	1.00	6.60	45.70
Max DO% Sat	91.30	100.80	126.30	82.10	116.60	103.00
Avg DO %Sat	60.27	62.39	92.75	42.67	43.14	72.05
Min Sp. Cond	209.33	90.13	184.51	149.00	45.60	99.56
Max Sp. Cond	17409.25	18201.46	29663.99	10900.00	12620.00	18300.00
Avg Sp. Cond	4068.55	3775.26	14892.97	2917.46	2900.48	5434.35
Min Salinity	0.10	0.04	0.09	0.10	0.02	0.05
Max Salinity	10.77	11.33	19.16	6.20	7.20	10.80
Avg Salinity	2.42	2.20	8.98	1.63	1.62	3.52
Total Samples	128	312	102	300	312	216

Table 44. Correlations of the short-term 24-hour datasondes deployments – temperature (^{o}C), dissolved oxygen (DO mg/L), and specific conductance (in μmhos/cm) – with the first 2 principal components, percent variation (cumulative percentage) for each principal component, and eigenvalues for Tres Palacios River and Carancahua Creek.

Principal Component	**Cumulative Percent**	**Eigenvalue**	**Temp**	**DO mg/L**	**Sp. Cond**
PC1	38.8	1.17	-0.367	0.785	0.498
PC2	75.7	1.10	0.751	-0.066	0.657

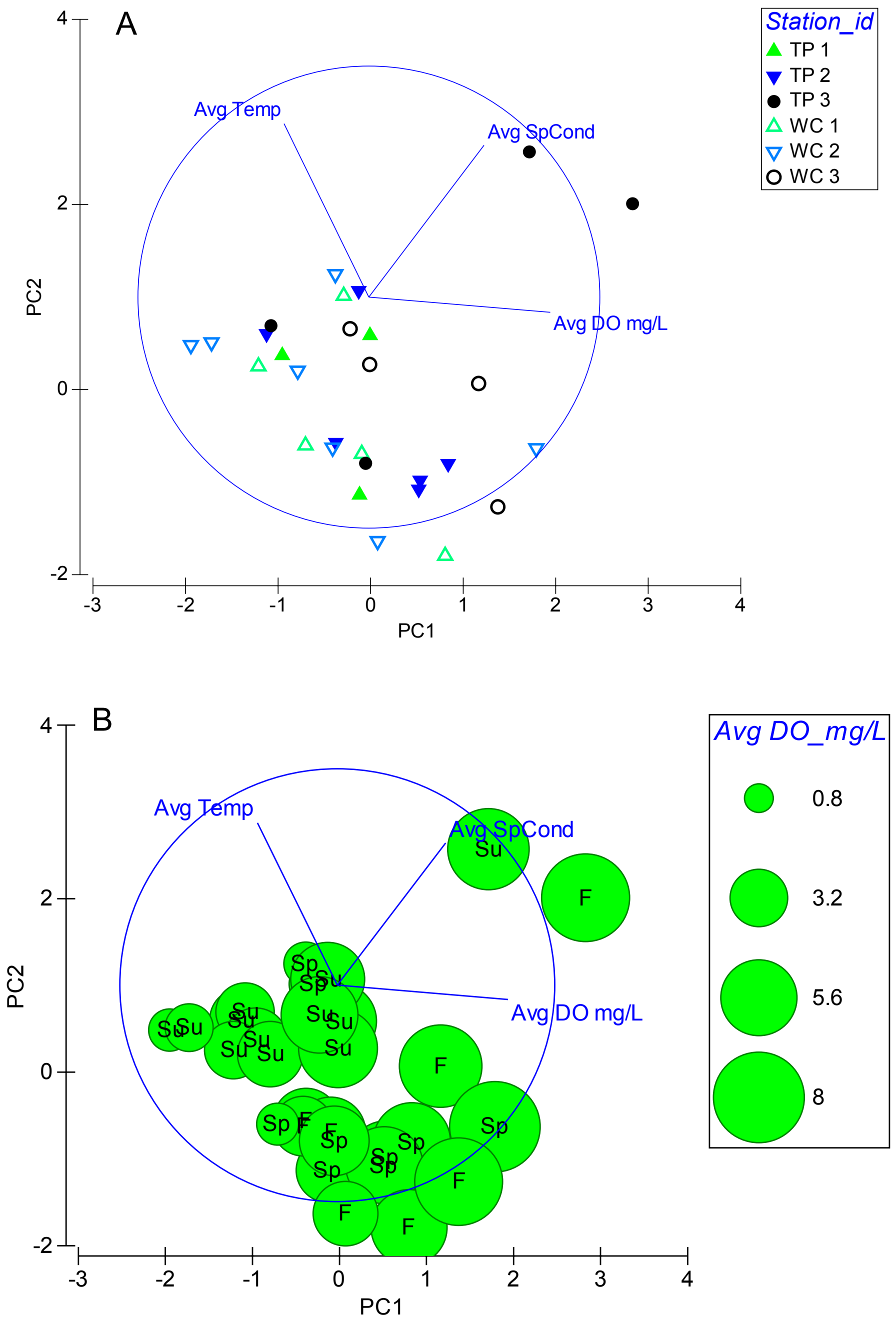


Figure 21. Ordination of stations based on principal components analysis of the short-term 24 hour datasondes deployments. A = Stations configuration with vector overlays of the variables used in the analysis. Length and direction of each vector reflects variable loading on each principal component. B = Configuration identical to A, but overlaid are average dissolved oxygen values for each observation (size of each circle is represented by the scale in the Figure) as well as season of collection designation (Sp = spring, Su =summer, F = fall).

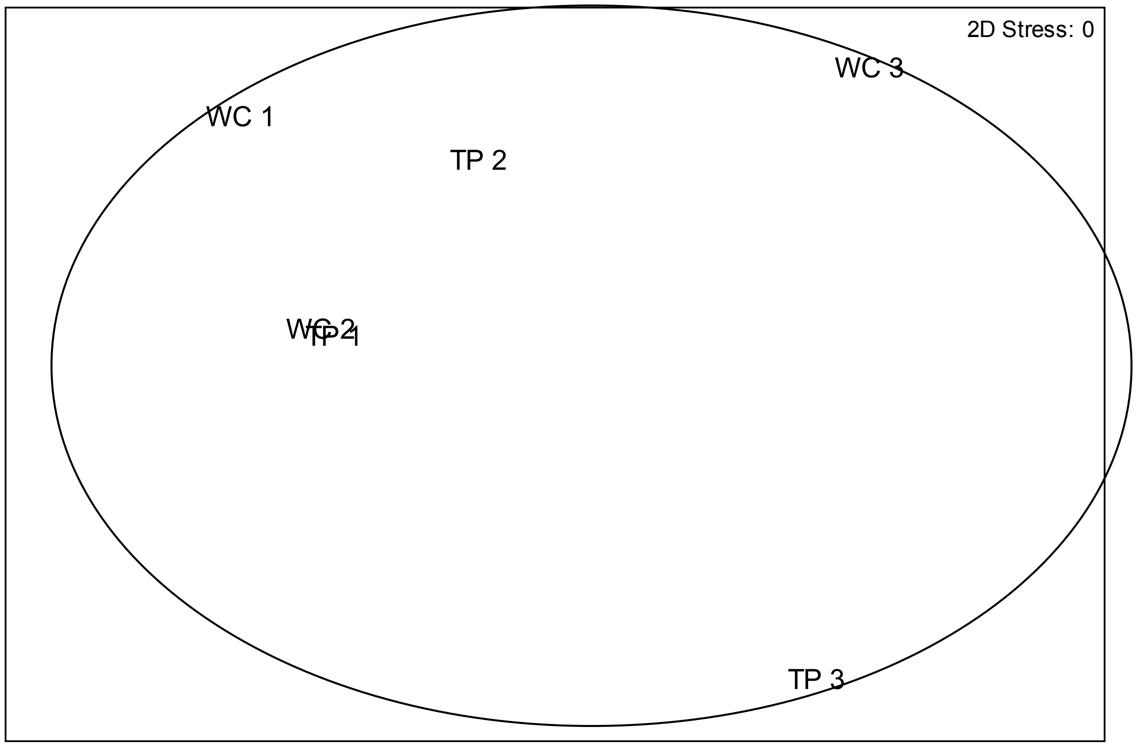


Figure 22. Means plot MDS ordination of the stations based on short-term 24 hour datasondes deployments taken from Tres Palacios River and Carancahua Creek. Stations within an ellipse are not significantly different based on ANOSIM comparisons among the study streams (p > 0.05).

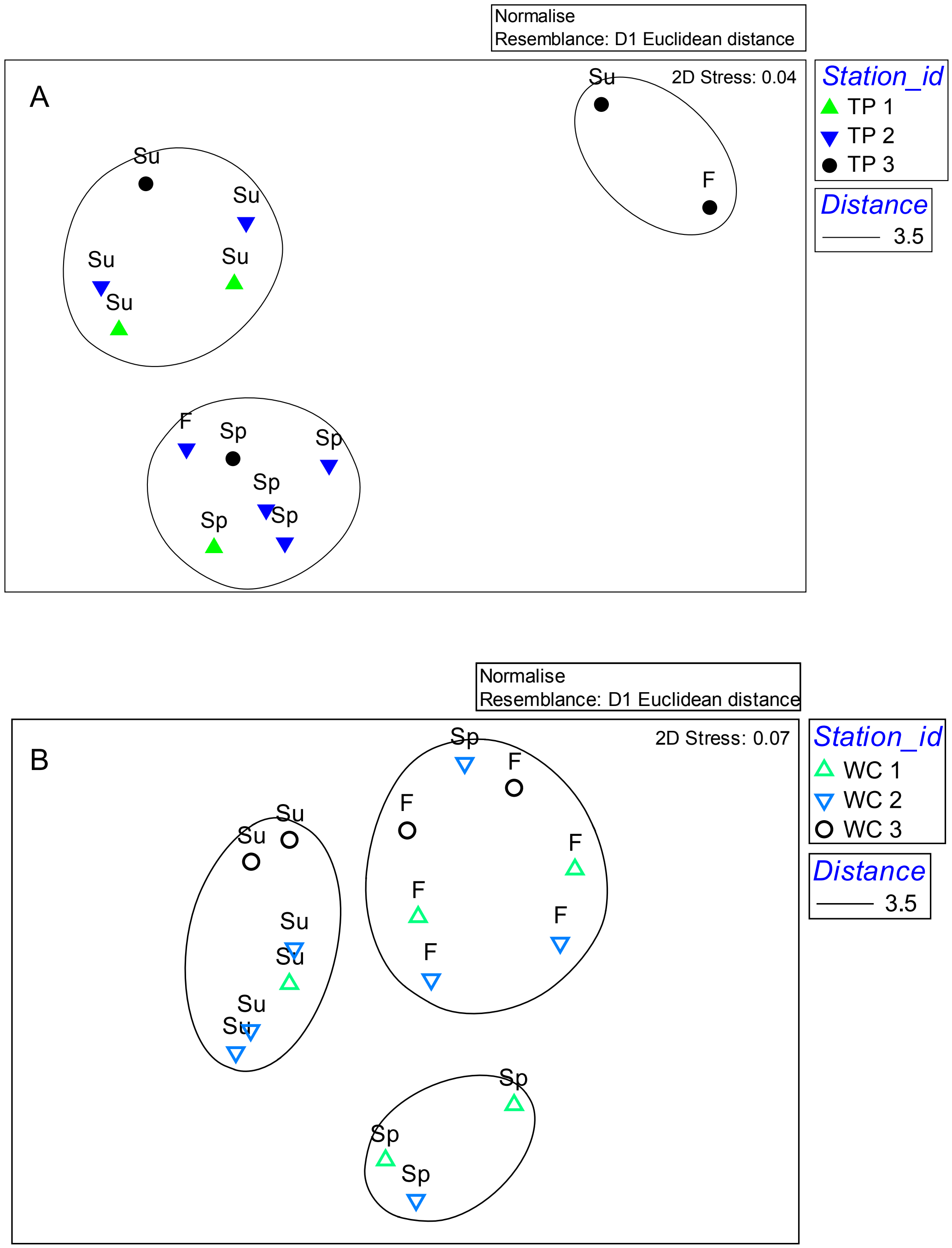


Figure 23. MDS configurations of stations based on short-term 24 hour datasondes deployments. A = Tres Palacios River only; and B = Carancahua Creek only. Overlaid on each configuration are the season of collection designation (Sp = spring, Su =summer, F = fall). Distance = 3.5 ellipses from cluster analysis of the same data (Figure not shown).

Short-Term 24-Hour Deployments – Garcitas and Carancahua Creeks

Datasonde deployments were more successful at Garcitas Creek, with a total of 38 of the 72 sampling events (52.8%) having a complete 24 hour record. Every station on Garcitas Creek had at least one successful sonde deployment during each season. For the duration of this study, only the lower station on Carancahua Creek during the spring season of both years was without any datasondes records. A summary of these short-term deployments is presented in Table 45.

Sondes deployments were analyzed with a principal components analysis, and those results are shown in Fig. 24. The first 2 principal components explained 78.8% of the total variation (Table 46). The well established negative relationship between water temperature and dissolved oxygen concentration can be seen in the configuration of stations along the first principal component (Fig. 24). Similar to the pattern seen within the Tres Palacios study stream, stations most negatively correlated with the first principal component tended to be summer collections taken during low salinity and warm water temperatures conditions. Again, these conditions were not unique to the reference stream, as upper, middle, and lower stations from each stream can be found on the lower left-hand quadrant of Fig. 24 (warmest surface temperatures and lowest dissolved oxygen values; samples typically representative of summer collections).

ANOSIM of the datasonde deployments revealed that no differences among the stations could be detected (Global R = 0.091, p = 0.057, see Fig. 25). While not significantly different because of the high degree of variability within each station (see Table 45), the means plot MDS configuration shown in Fig. 24b is still informative in that it captures the low dissolved oxygen conditions that were common on each of the Garcitas Creek stations (the x-axis of Fig. 24 can be viewed as a continuum of DO values from low to high). The upper, middle, and lower stations on Garcitas Creek fall within the extremes of the reference stream (WC 1 and WC 2 having extreme hypoxic conditions and WC 3 never experiencing hypoxia during the course of this study). Even the lowest station on Garcitas Creek experienced low dissolved oxygen values around 2 mg/L, and this could be attributed to the increased water depth found at this station. The depth at Garcitas lowest station was ~ 3m where as the depth at the other mid-coast streams was ~1m. As a result the water was easily mixed by wind in Tres Palacios and Carancahua but could stratify in Garcitas. Within each study stream, no differences among the stations could be detected (Garcitas Creek Global R = 0.068, p = 0.183; Carancahua Creek Global R = 0.038, p = 0.307)

Table 45. Summary statistics of the short-term 24 hour datasonde deployments by station for Garcitas and Carancahua Creeks. Specific Conductance (Sp. Cond) in μmhos/cm, salinity in PSU.

	GC 1	GC 2	GC 3	WC 1	WC 2	WC 3
Min Temp ^{o}C	17.95	18.79	19.62	17.91	17.97	19.06
Max Temp ^{o}C	32.34	32.16	31.70	30.39	31.05	32.82
Avg Temp ^{o}C	25.76	25.99	26.08	24.62	25.71	25.87
Min DO mg/L	0.42	1.24	2.01	0.08	0.50	4.61
Max DO mg/L	11.34	6.13	7.02	7.48	9.80	8.22
Avg DO mg/L	5.11	4.67	5.11	3.58	3.59	6.27
Min DO %Sat	5.60	16.70	28.17	1.00	6.60	45.70
Max DO% Sat	129.00	88.30	104.00	82.10	116.60	103.00
Avg DO %Sat	62.35	57.96	64.55	42.67	43.14	72.05
Min Sp. Cond	9.96	74.24	84.82	149.00	45.60	99.56
Max Sp. Cond	11331.80	19400.00	22600.00	10900.00	12620.00	18300.00
Avg Sp. Cond	2605.59	4518.76	9952.76	2917.46	2900.48	5434.35
Min Salinity	0.01	0.03	0.04	0.10	0.02	0.05
Max Salinity	6.77	11.50	14.11	6.20	7.20	10.80
Avg Salinity	1.48	2.61	6.49	1.63	1.62	3.52
Total Samples	408	384	312	300	312	216

Table 46. Correlations of the short-term 24-hour datasondes deployments – temperature (^{o}C), dissolved oxygen (DO mg/L), and specific conductance (in μmhos/cm) – with the first 2 principal components, percent variation (cumulative percentage) for each principal component, and eigenvalues for Garcitas and Carancahua Creeks.

Principal Component	Cumulative Percent	Eigenvalue	Temp	DO mg/L	Sp. Cond
PC1	49.3	1.48	-0.645	0.621	-0.446
PC2	78.8	0.88	0.233	0.396	0.888

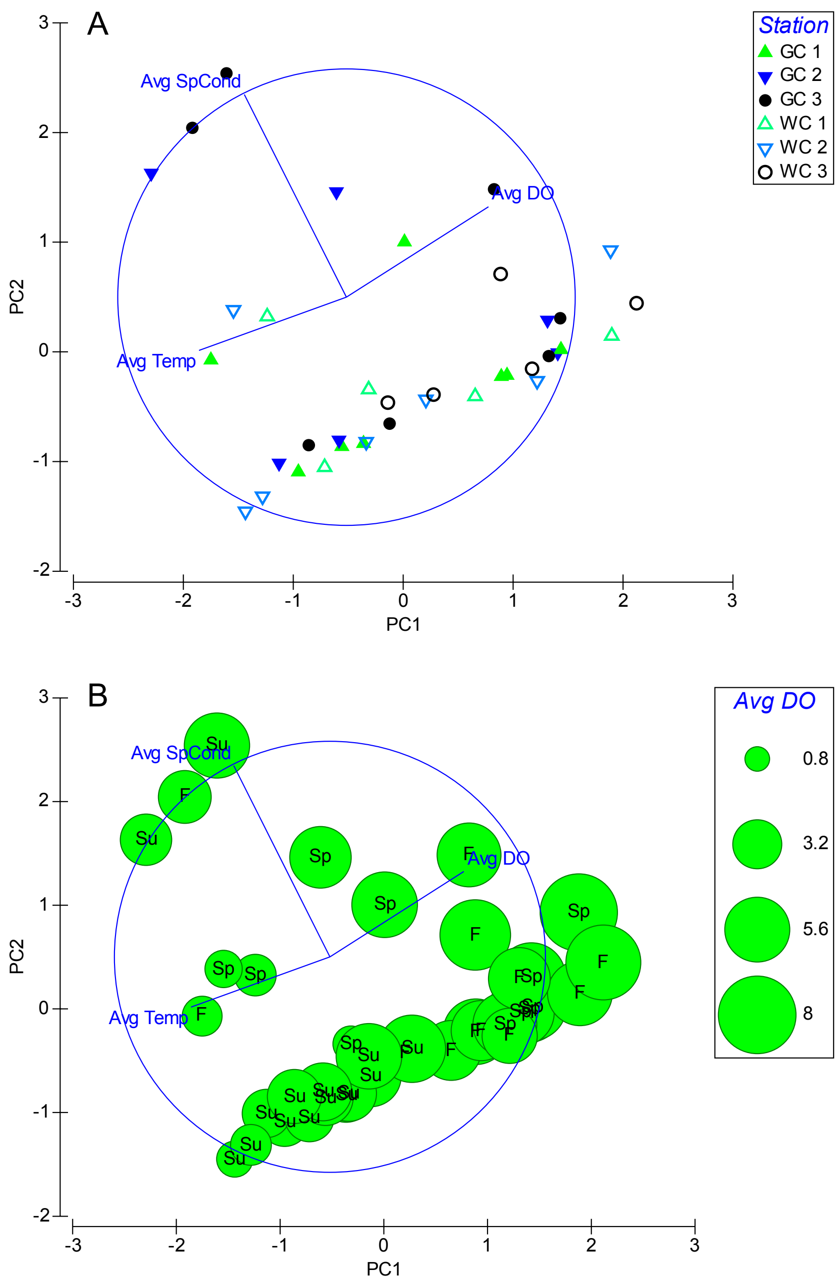


Figure 24. Ordination of stations based on principal components analysis of the short-term 24 hour datasondes deployments at Garcitas and Carancahua Creeks. A = Stations configuration with vector overlays of the variables used in the analysis. Length and direction of each vector reflects variable loading on each principal component; B = Configuration identical to A, but overlaid are average dissolved oxygen values for each observation (size of each circle is represented by the scale in the Figure) as well as season of collection designation (Sp = spring, Su =summer, F = fall).

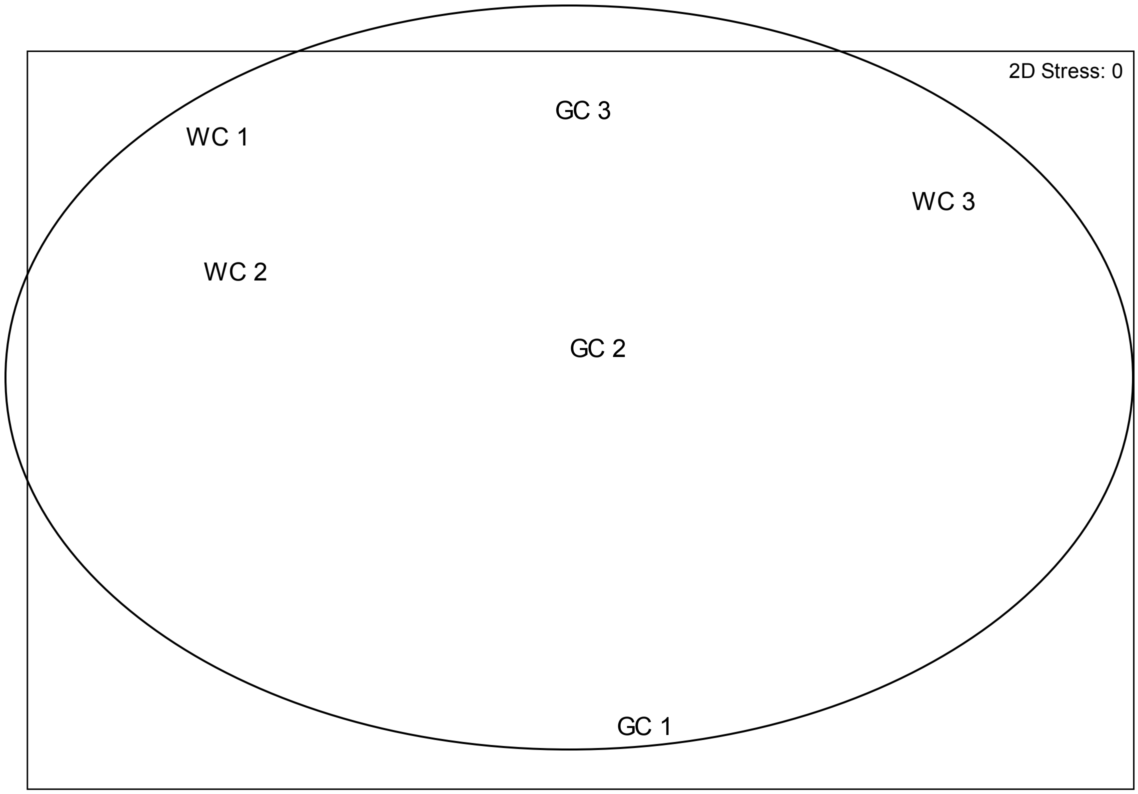


Figure 25. Means plot MDS ordination of the stations based on short-term 24 hour datasondes deployments taken from Garcitas and Carancahua Creeks. Stations within an ellipse are not significantly different based on ANOSIM comparisons among the study streams (*p* > 0.05).

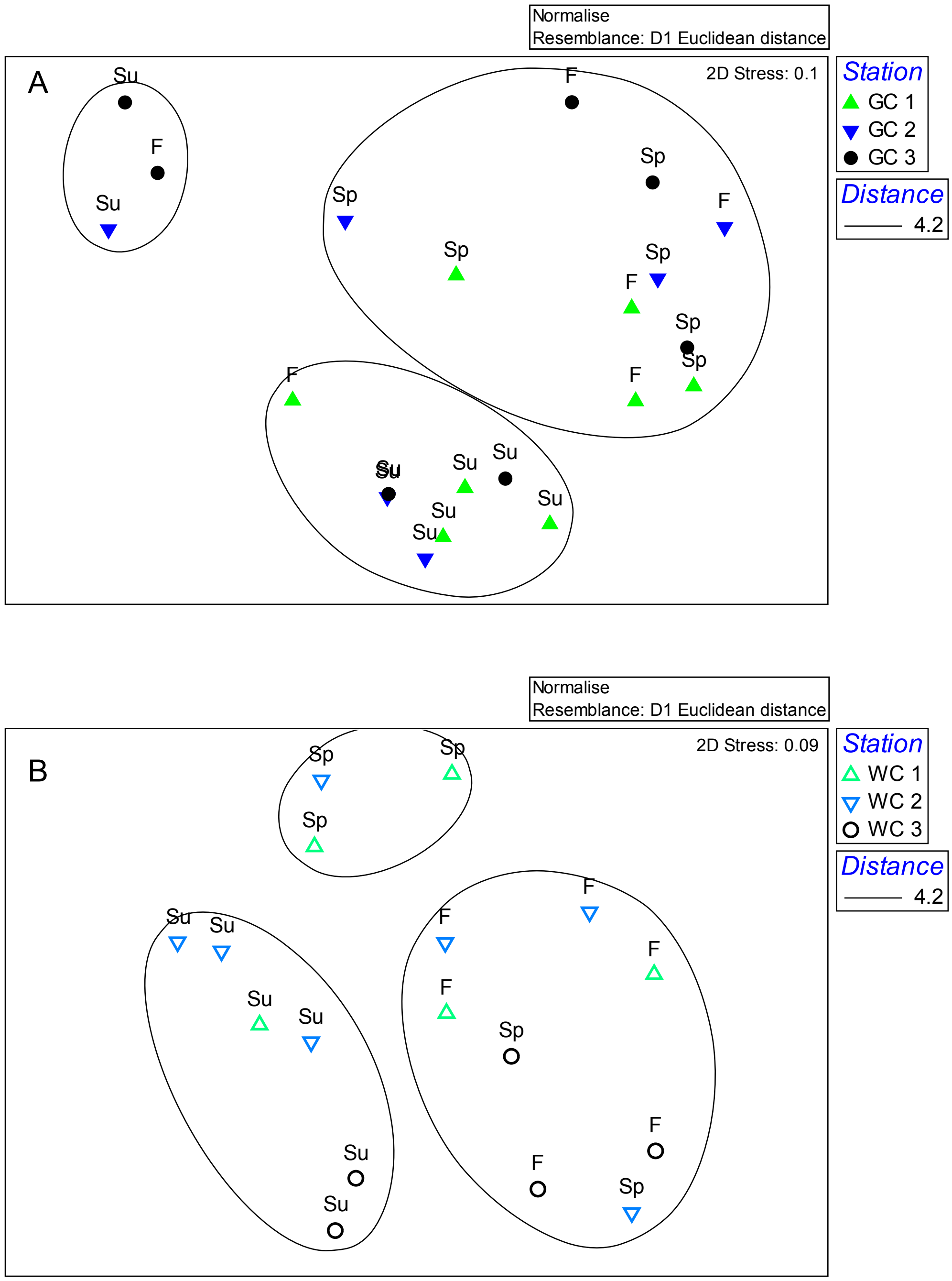


Figure 26. MDS configurations of stations based on short-term 24 hour datasondes deployments. A = Garcitas Creek only; and B = Carancahua Creek only. Overlaid on each configuration are the season of collection designation (Sp = spring, Su =summer, F = fall). Distance = 4.2 ellipses from cluster analysis of the same data (Figure not shown).

although a significant difference among seasons was evident within both study streams (Garcitas Creek Global R = 0.291, p = 0.002; Carancahua Creek Global R = 0.668, p = 0.001; see Fig. 26). In each comparison, the summer collections were the factor responsible for the significant differences seen. The configuration for Carancahua Creek seen in Fig. 26b are the same data presented in Fig.24b, but the stations in Fig. 26b have been rotated to match the ordinations displayed by the principal component analysis results of Fig.24a.

Water and Sediment Samples – Tres Palacios and Carancahua Creek

Surface water samples were collected on each sampling trip and a summary of those data are presented in Table 47. Three variables were highly correlated and determined to be redundant within the principle components analysis. Volatile residue or Volatile Suspended Solids (VSS) and residue-dry or Total Dissolved Solids (TDS) were each highly correlated with residue or Total Suspended Solids (TSS) values, and sulfate was highly correlated with chloride. Volatile residue, residue-dry, and sulfate were dropped from the analysis.

Based on a principal components analysis, the first 3 components explained 64.2 % of the total variation (Table 48). The first component is reflective of overall inflow conditions, with increased chloride, fluoride, nitrite, and alkalinity loading most positively along the x-axis (Fig. 27a). Most all the stations on the positive side of component 1 tended to be middle and lower stations where higher salinities were most common. Total organic carbon loaded negatively on component one, and these conditions were more indicative of lower salinity conditions. The second component is a measure of overall nutrient loading, with total Kjeldahl nitrogen, TSS, phosphorus, and biological oxygen demand loading most positively. The combination of these two components (inflows and nutrient loads) accurately captures each flooding event that was sampled during the course of this study (Fig.27b).

ANOSIM tests of the surface water quality measurements revealed that within each stream, no significant differences could be detected among the upper, middle, or lower stations (Tres Palacios Global R = 0.008, p = 0.400, and Carancahua Creek Global R = -0.113, p = 0.980). While Tres Palacios lacked any significant seasonality factor (Global R = -0.013, p = 0.540), Carancahua Creek did have some degree of seasonality in surface water quality measurements (Global R = 0.274, p = 0.003). The spring season was significantly different from both the summer and the fall seasons. MDS configuration of the stations (rotated to match the pattern seen in the principal components plot of Fig.27a) is shown in Fig. 28a, with the flooding event samples identified within the ellipse. Lacking any significant station difference within each stream, all samples from a common stream were pooled together and further identified as either impacted (Tres Palacios) or control (Carancahua

Table 47. Surface-water quality parameters by station for Tres Palacios River and Carancahua Creek. Data are means (n=12, unless otherwise noted). Standard deviations are presented in parentheses.

	TP 1	**TP 2**	**TP 3**	**WC 1** [a]	**WC 2** [a]	**WC 3** [a]
BOD	3.25 (0.4)	3.42 (0.5)	4.00 (1.6)	3.10 (0.3)	3.01 (0.3)	3.46 (1.2)
ALK	125.8 (60.5)	120.83 (58.2)	112.55 (46.8)	94.40 (47.1)	97.00 (44.1)	91.73 (40.1)
TSS	80.67 (145.5)	101.58 (187.4)	217.64 (321.9)	31.30 (30.7)	37.46 (32.3)	57.00 (27.8)
VSS	11.50 (17.1)	14.67 (20.0)	32.55 (38.7)	6.80 (3.4)	7.55 (3.9)	11.55 (4.7)
Ammonia	0.07 (0.1)	0.72 (0.1)	0.07 (0.1)	0.07 (0.1)	0.07 (0.1)	0.06 (0.1)
Nitrite	0.10 (0.1)	0.09 (0.1)	0.17 (0.2)	0.06 (0.01)	0.06 (0.1)	0.09 (0.1)
Nitrate	0.77 (0.9)	0.72 (0.9)	0.35 (0.3)	0.37 (0.5)	0.36 (0.5)	0.29 (0.3)
Total N	1.12 (0.3)	1.25 (0.4)	1.67 (0.7)	1.08 (0.2)	1.15 (0.2)	1.38 (0.3)
Phosphorus	0.27 (0.2)	0.25 (0.2)	0.34 (0.2)	0.29 (0.2)	0.27 (0.2)	0.29 (0.1)
TOC	6.67 (1.5)	6.58 (1.2)	5.27 (1.7)	8.30 (1.5)	8.09 (1.4)	7.27 (1.5)
Chloride	445.50 (719.5)	618.67 (832.5)	3211.64 (2938.0)	512.20 (876.6)	667.82 (1002.9)	1584.46 (1862.6)
Sulfate	67.17 (98.6)	90.17 (115.0)	443.2 (406.9)	71.60 (119.1)	93.18 (136.8)	217.9 (258.3)
Fluoride	0.29 (0.1)	0.29 (0.1)	0.40 (0.2)	0.22 (0.1)	0.24 (0.1)	0.26 (0.1)
Chl_a	13.3 (15.4)	15.2 (13.8)	19.38 (28.8)	13.93 (11.8)	12.70 (12.3)	18.76 (27.5)
Pheo_a	24.48 (33.7)	13.2 (21.9)	16.84 (22.3)	8.57 (10.5)	13.8 (17.9)	25.18 (32.2)
TDS	1041.25 (1333.3)	1364.67 (1566.6)	5588.64 (5048.2)	1093.50 (1508.8)	3242.18 (5905.8)	3174.46 (3525.9)
Orthophosphate	0.15 (0.1)	0.14 (0.1)	0.32 (0.2)	0.20 (0.1)	0.19 (0.1)	0.19 (0.1)

[a] n=11, No Water Column Profiles taken during the May 2004 flooding event at WC 1, WC 2, or WC 3.

Table 48. Correlations of the surface water quality measurements with the first 3 principal components, percent variation (cumulative percentage) for each principal component, and eigenvalues for Tres Palacios River and Carancahua Creek.

	PC 1	**PC 2**	**PC 3**
Cumulative Percent	32.6	52.5	64.2
Eigenvalue	4.56	2.78	1.64
BOD	0.226	0.343	0.324
ALK	0.374	-0.209	0.001
TSS	-0.089	0.517	-0.160
Ammonia	-0.014	0.041	-0.548
Nitrite	0.365	0.130	0.060
Nitrate	-0.021	0.098	-0.003
Total N	0.092	0.535	-0.084
Phosphorus	-0.294	0.388	-0.095
TOC	-0.377	-0.177	0.092
Chloride	0.395	0.096	-0.126
Fluoride	0.442	-0.061	-0.081
Chl_a	0.142	0.166	0.579
Pheo_a	0.238	-0.095	-0.369
Orthophosphate	0.054	0.209	-0.216

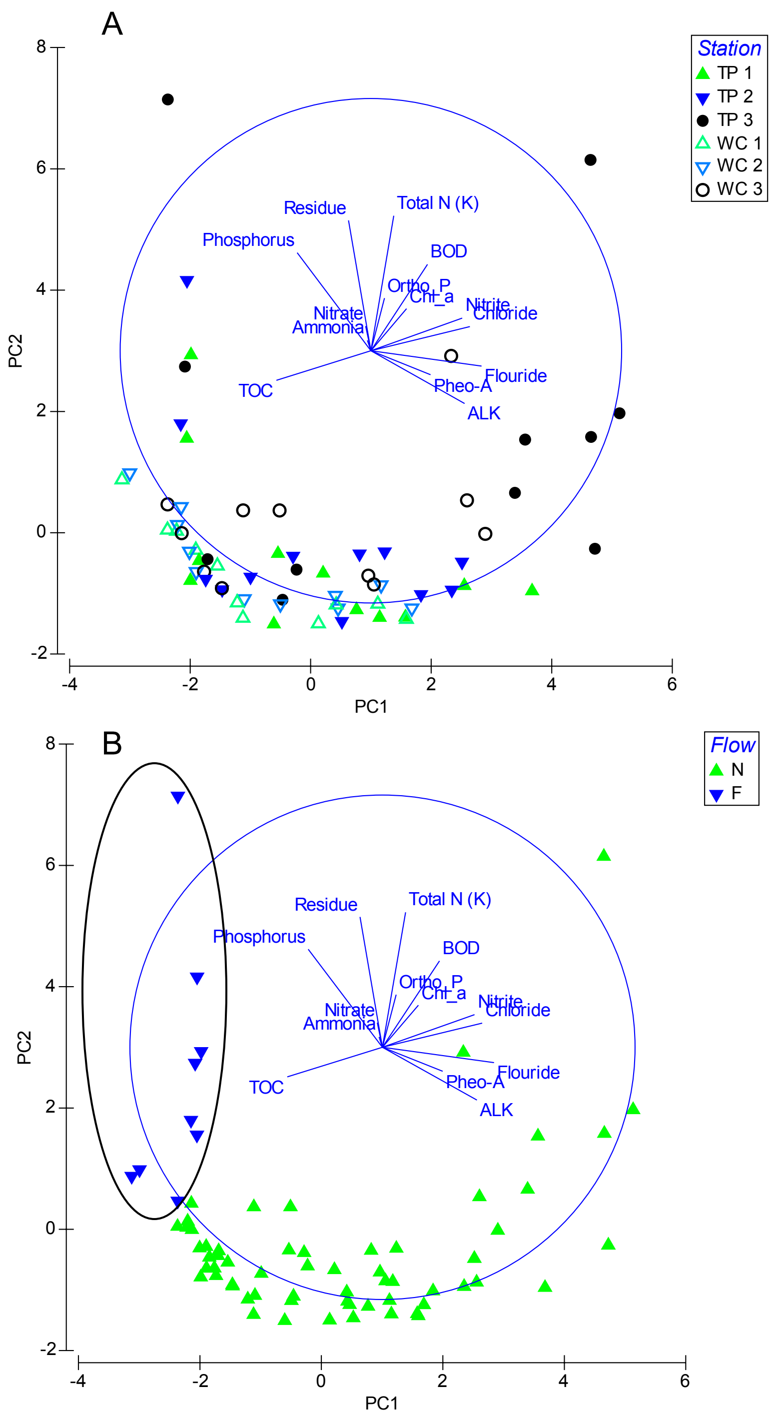


Figure 27. Ordination of the stations based on principal components analysis of surface water quality collections from Tres Palacios River and Carancahua Creek. A = Stations configuration with vector overlays of the variables used in the analysis (vectors have been shifted from the graph origin to aid in interpretation); B = Configuration identical to A, but overlaid with designations of flow conditions during sampling events (N = normal flow, F = flooding conditions). Flood samples enclosed within the ellipse.

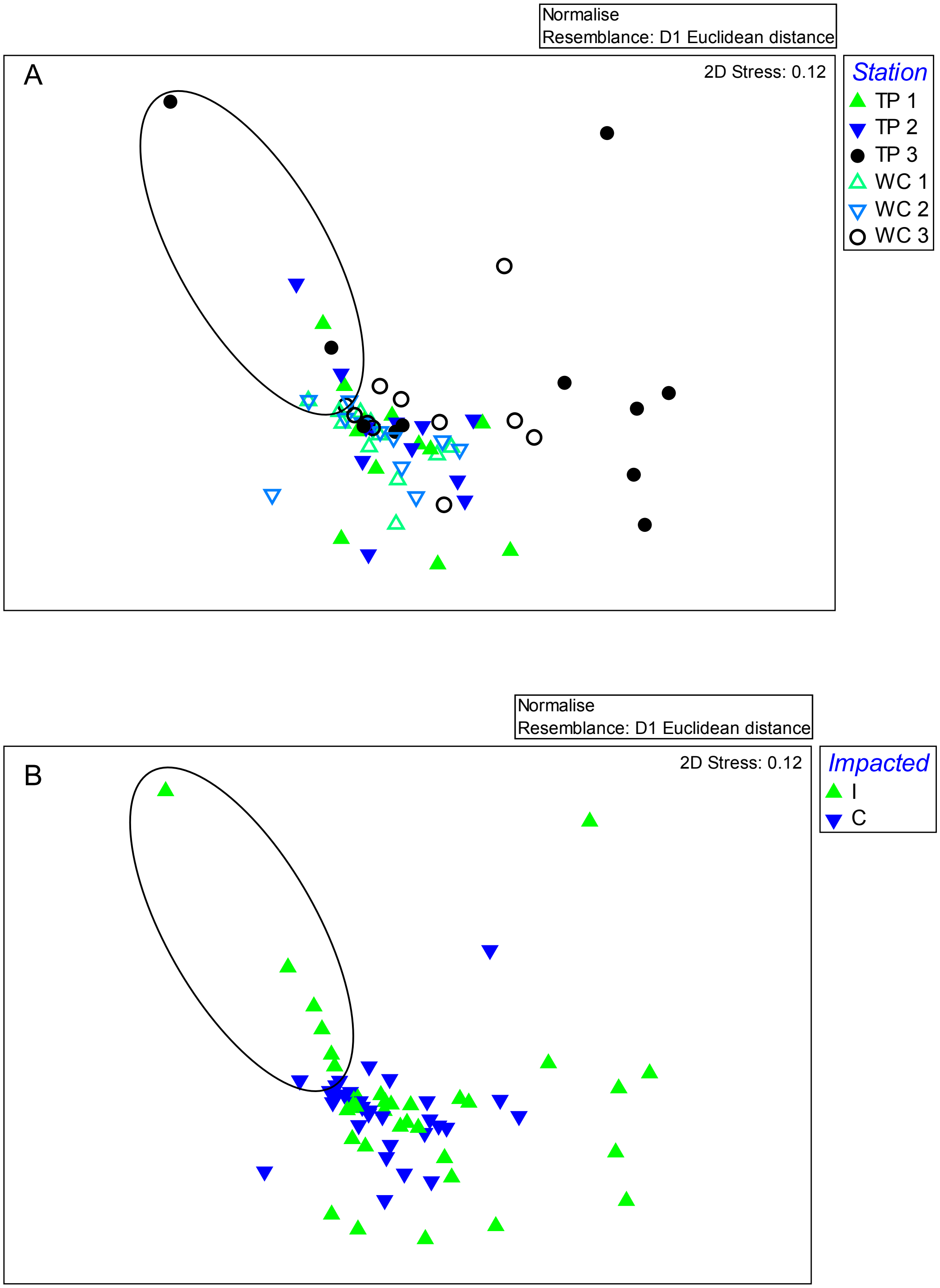


Figure 28. A = MDS configurations of stations based on surface water quality measurements. Flood samples enclosed within the ellipse; B = Identical configuration as A, but overlaid with designations of level of Impact (Impacted stream I = Tres Palacios, Control stream C = Carancahua Creek).

Creek), then reanalyzed to look for significant differences between the streams. No differences in overall surface water quality was detected between Tres Palacios and Carancahua Creek (Global R = 0.046, p = 0.089; see Fig. 28b).

Surface water quality measurements were related to bottom water quality measurements within each stream (Spearman's rank correlations of the underlying resemblance matrices), and significant correlations were found within both Tres Palacios (ρ_S = 0.667; *prob*. = 0.001) and Carancahua Creek (ρ_S = 0.699; *prob*. = 0.001). Summary statistics for the bottom water quality measurements are presented in Table 49. Principal component analysis results of bottom water measurements were nearly identical to those of the surface water collections, revealing the importance of inflows (i.e., salinity as measured by chloride) and the influx of nutrients into each stream (total Kjeldahl nitrogen, phosphorus, and TSS; see Fig. 29) as the factors configuring the stations within the space defined by the first two principal components. Less evidence of vertical stratification was seen in the water quality parameters than was seen in the water column profiles of field parameters.

Sediment samples were collected only once per season, although sediment samples from the stream middle and stream side were analyzed separately. No sediment samples were collected during flooding conditions. Summary statistics for the middle collections are presented in Table 50. The first two principal components explain 84.9 % of the variation (Table 51), with the greatest degree of separation of the stations revealed in percent sand or percent clay compositions. Percent solids and percent sand were highly correlated in the sediments collected from the middle of both streams (Fig. 30). Large amounts of gravel (significant constituent of the second principal component) were only found at the upper-most stations on each stream, and the greatest amounts of gravel were found after substantial flooding had occurred.

ANOSIM results did not reveal any consistent gradients in the sediment composition found in either study stream (Fig. 30). The means plot of Fig. 31 has been rotated to match the stations configuration results seen in the principal component analysis (general gradient from fine sediments of clays and silts to coarser sediments of sands along the x-axis), and inspection of both of these Figures shows that sediment composition of the upper, middle, and lower stations can be very different within each stream. For example, the lower station on Tres Palacios had low total organic carbon and high sand content, while the same lower-most station on Carancahua Creek had much higher total organic carbon and very low sand content. The exact opposite is found at the sampling stations just upstream, as total organic carbon and percent sand composition switched to elevated on Tres Palacios and lower on Carancahua Creek (Fig. 31).

Summary statistics for the side channel collections are presented in Table 52. The first two principal components explained 74.8 % of the variation (Table 53), and similar to the results for the mid-channel collections, this component separated the stations with respect to their percent sand or percent clay properties (Fig. 32). Percent sand values were typically higher in the side sediments when compared to the mid-channel collections. Finer composition sediments were found primarily on Tres Palacios, with the highest percent silt and percent clay fraction found in the lower-most station on this stream. Organic carbon content in the side sediments was higher on Tres Palacios, with the lower-most station having close to three times the concentrations of organic carbon found within any station on the reference stream. When compared to the mid-channel collections, total organic carbon content of the side channel collections was well below that taken from the middle.

ANOSIM results of the side channel collections also did not reveal any consistent gradients in the sediment composition found in either study stream (lower, middle, and upper stations are generally not arranged closer to one another within the MDS plot, see Fig. 33). The overall gradient within the means plot of Fig. 33 (along a diagonal from lower left to upper right consisting of fine sediments of clay and silt with higher TOC to coarser sediments of sand and lower TOC) shows that sediment compositions at each station within each stream can be dramatically different from the side of the stream to the middle of the stream (compare station configurations along the common x-axis gradient of sediment compositions for Figures 30 and 32).

Water and Sediment Samples – Garcitas and Carancahua Creek

Summary statistics for surface water quality collections from Garcitas and Carancahua Creeks are presented in Table 54. The three variables of volatile residue (VSS), residue-dry (TDS), and sulfate were again highly correlated with residue (TSS) and chloride values, and these were excluded from the principal component analysis.

The first three principal components explained 60.2 % of the total variation (Table 55). Similar to the salinity-driven explanation of variation seen in analysis of water quality collections from Tres Palacios, the first component involving Garcitas Creek is also reflective of overall inflow conditions, with increased chloride, fluoride, nitrite, and alkalinity loading positively along the x-axis (Fig. 34a). Total organic carbon was the only variable to load significantly negative on the first component. The second component can be viewed as a measure of overall productivity, with biological oxygen demand, chlorophyll a, total Kjeldahl nitrogen, and nitrate loading most positively. While explaining only 48.0% of the total variability, the combination of these two components (inflows and nutrient loads) again reveals the uniqueness of the environmental conditions prevalent during flooding (Fig. 34b).

ANOSIM tests again failed to find any significant differences in surface water quality parameters among the upper, middle, or lower stations within each stream (Garcitas Creek Global R = -0.208, p = 0.999, and Carancahua Creek

Table 49. Bottom-water quality parameters by station for Tres Palacios River and Carancahua Creek. Data are means (n=12, unless otherwise noted). Standard deviations are presented in parentheses.

	TP 1 [a]	**TP 2** [a]	**TP 3** [b]	**WC 1** [a]	**WC 2** [a]	**WC 3** [a]
BOD	3.00 (0.00)	3.00 (0.00)	3.0 (0.00)	3.01 (0.3)	3.00 (0.00)	3.55 (1.5)
ALK	127.36 (52.4)	124.91 (51.4)	93.75 (35.3)	97.64 (47.8)	95.55 (42.9)	92.27 (40.5)
TSS	113.09 (223.9)	70.27 (79.5)	109.50 (124.5)	91.46 (154.9)	45.91 (30.8)	178.82 (243.7)
VSS	14.82 (24.6)	10.73 (9.2)	15.50 (11.8)	12.00 (16.1)	7.18 (3.4)	28.55 (41.6)
Ammonia	0.13 (0.1)	0.16 (0.1)	0.08 (0.1)	0.26 (0.2)	0.17 (0.1)	0.06 (0.1)
Nitrite	0.13 (0.1)	0.12 (0.1)	0.19 (0.2)	0.08 (0.1)	0.07 (0.1)	0.11 (0.1)
Nitrate	0.75 (0.8)	0.55 (0.6)	0.35 (0.4)	0.39 (0.6)	0.37 (0.5)	0.28 (0.3)
Total N	1.27 (0.5)	1.21 (0.3)	1.39 (0.3)	1.48 (0.6)	1.32 (0.3)	1.48 (0.4)
Phosphorus	0.30 (0.2)	0.29 (0.2)	0.32 (0.2)	0.35 (0.2)	0.31 (0.2)	0.32 (0.1)
TOC	6.46 (1.6)	6.27 (1.3)	5.50 (2.4)	8.09 (1.9)	7.91 (1.7)	7.09 (1.4)
Chloride	852.18 (1443.5)	1228.46 (1621.2)	3370.50 (3424.7)	953.91 (1342.2)	933.55 (1203.4)	1683.46 (1921.1)
Sulfate	122.91 (194.9)	173.00 (220.1)	464.25 (476.4)	131.18 (181.7)	128.64 (163.7)	231.91 (267.2)
Fluoride	0.31 (0.1)	0.32 (0.1)	0.37 (0.2)	0.23 (0.1)	0.24 (0.1)	0.28 (0.2)
TDS	1804.27 (2632.5)	2550.64 (3099.8)	5564.50 (5350.2)	1952.18 (2428.7)	1876.00 (2144.2)	3325.09 (3649.3)
Orthophosphate	0.18 (0.1)	0.18 (0.1)	0.49 (0.3)	0.23 (0.1)	0.22 (0.1)	0.22 (0.1)

[a] n=11, No Bottom Water Quality samples collected during the May 2004 flooding event.
[b] n=4, Bottom Water Quality samples not normally taken at TP 3 due to shallow conditions at this station.

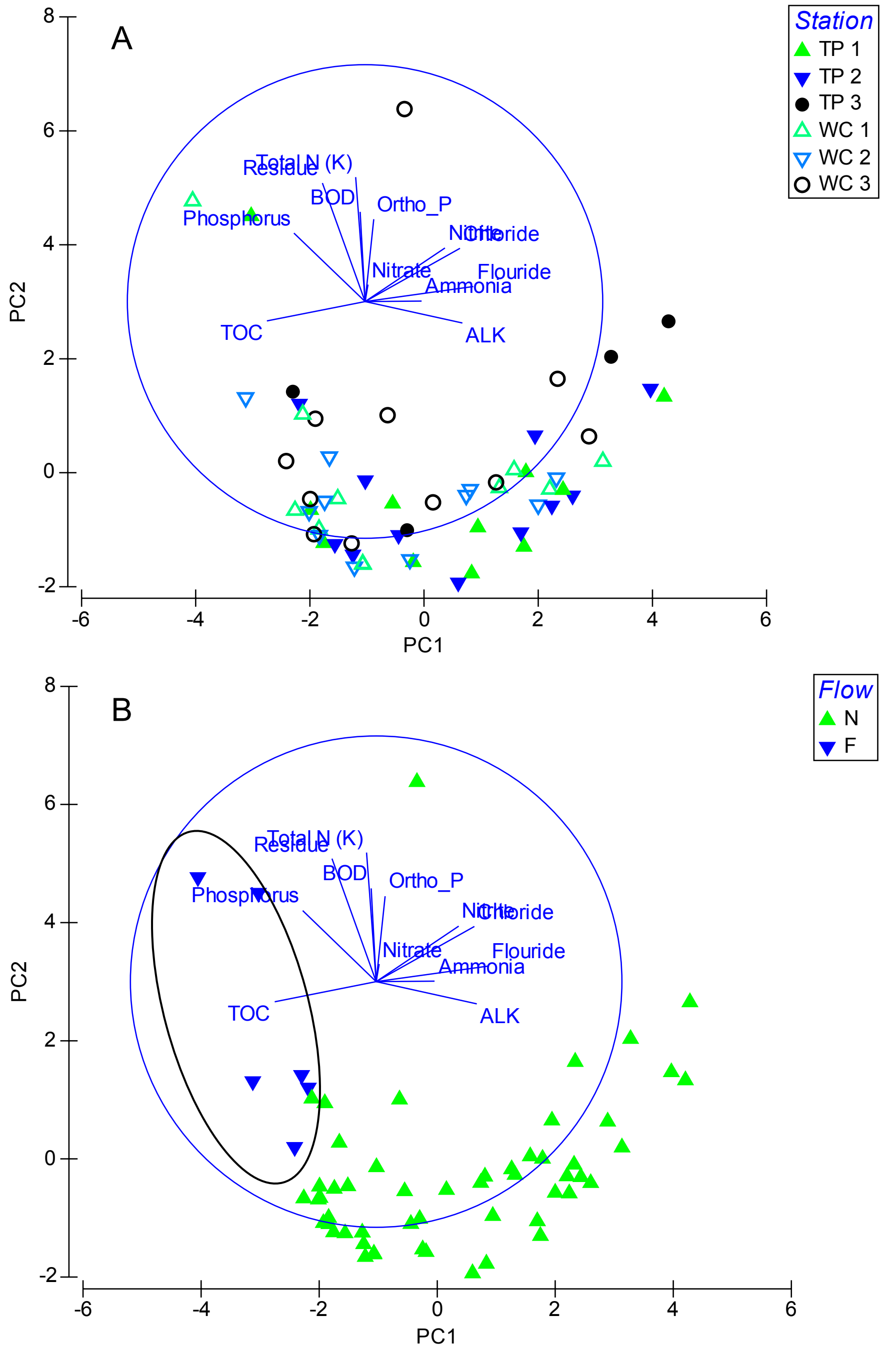


Figure 29. Ordination of the stations based on principal components analysis of bottom water quality collections from Tres Palacios River and Carancahua Creek. A = Stations configuration with vector overlays of the variables used in the analysis (vectors have been shifted from the graph origin to aid in interpretation); B = Configuration identical to A, but overlaid with designations of flow conditions during sampling events (N = normal flow, F = flooding conditions). Flood samples enclosed within the ellipse.

Table 50. Sediment parameters (mid-channel) by station for Tres Palacios River and Carancahua Creek. Data are means (n=6, unless otherwise noted). Standard deviations are presented in parentheses. Entries with a dash (-) are less than 0.01 %

	TP 1	**TP 2**	**TP 3**	**WC 1**	**WC 2**	**WC 3**
TOC Sed	21066.00 (3327.1)	12703.3 (6788.8)	9917.50 (5623.9)	11767.67 (7776.1)	8445.00 (5290.9)	15860.00 (4118.1)
% Solids	29.98 (8.7)	40.93 (17.1)	57.87 (9.6)	51.43 (22.7)	58.30 (19.0)	36.64 (10.9)
% Gravel	2.12 (4.7)	-	-	0.51 (1.2)	-	-
% Silt	16.48 (6.6)	14.24(10.3)	20.85 (4.7)	12.87 (13.8)	3.73 (6.6)	17.05 (2.8)
% Clay	65.01 (14.0)	60.83 (28.9)	30.95 (2.0)	39.96 (29.2)	23.15 (23.5)	64.66 (17.0)
% Sand	17.00 (19.3)	24.94 (33.5)	47.95 (5.1)	46.51 (40.9)	73.19 (29.0)	18.62 (17.8)

Table 51. Correlations of the sediment parameters (mid-channel) with the first 2 principal components, percent variation (cumulative percentage) for each principal component, and eigenvalues for Tres Palacios River and Carancahua Creek.

Principal Component	**Cumulative Percent**	**Eigenvalue**	**TOC Sediment**	**% Solids**	**%Gravel**	**% Silt**	**% Clay**	**% Sand**
PC1	68.5	4.11	-0.451	0.444	0.121	-0.360	-0.469	0.485
PC2	84.9	16.40	-0.105	-0.054	-0.970	0.180	0.092	-0.069

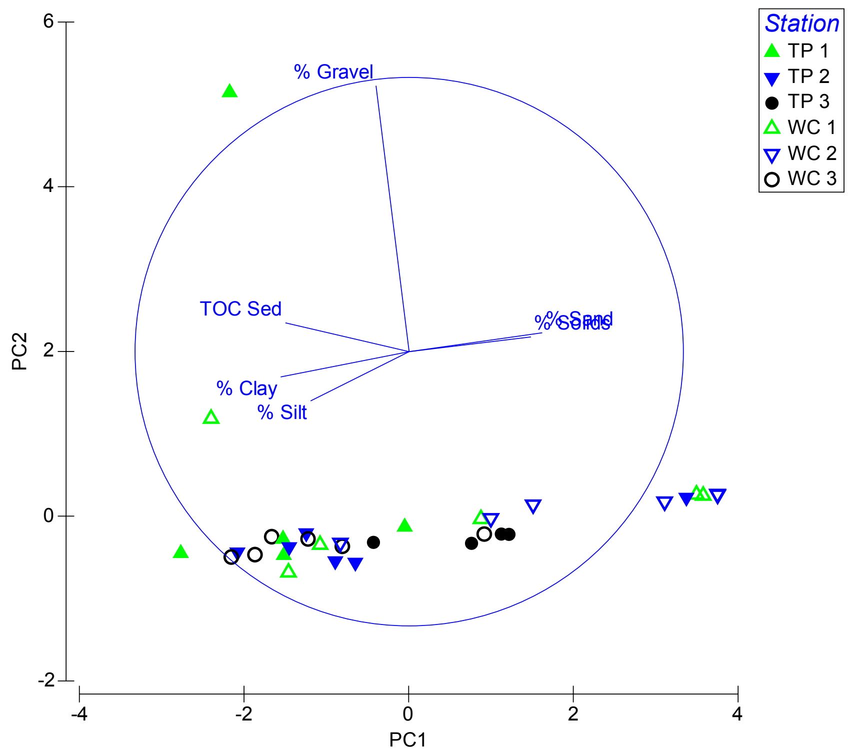


Figure 30. Ordination of the stations based on principal components analysis of sediment parameters (mid-channel) from Tres Palacios River and Carancahua Creek.

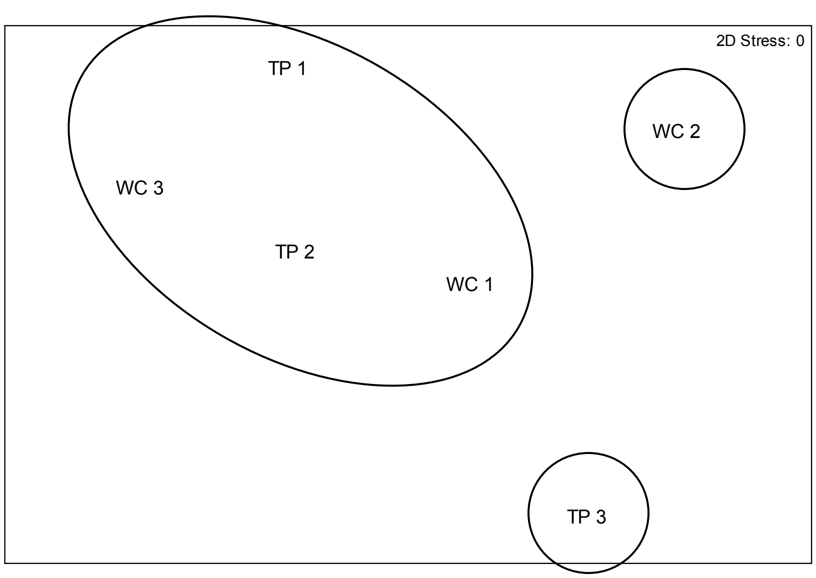


Figure 31. Means plot MDS ordination of the stations based on sediment parameters (mid-channel) taken from Tres Palacios River and Carancahua Creek. Stations within an ellipse are not significantly different based on ANOSIM comparisons ($p > 0.05$).

Table 52. Sediment parameters (side channel collection) by station for Tres Palacios River and Carancahua Creek. Data are means (n=6, unless otherwise noted). Standard deviations are presented in parentheses. Entries with a dash (-) are less than 0.01 %.

	TP 1	**TP 2**	**TP 3**	**WC 1**	**WC 2**	**WC 3**
TOC Sed	8168.40 (6137.7)	9179.44 (4839.7)	17870.03 (14358.9)	4598.65 (2550.1)	5672.97 (3545.3)	6724.14 (4211.4)
% Solids	58.46 (3.9)	62.98 (9.5)	49.66 (10.8)	68.42 (5.9)	61.18 (10.5)	64.13 (10.6)
% Gravel	1.11 (2.5)	-	0.21 (0.4)	-	7.45 (9.6)	-
% Silt	18.29 (4.7)	16.52 (6.5)	33.31 (7.9)	13.67 (9.9)	21.68 (9.2)	23.71 (8.7)
% Clay	37.10 (13.7)	27.23 (3.9)	40.62 (15.9)	16.81 (6.2)	25.62 (11.2)	23.09 (10.9)
% Sand	43.50 (20.3)	56.26 (7.6)	25.67 (11.1)	69.36 (15.5)	45.26 (22.0)	53.19 (18.1)

Table 53. Correlations of the sediment parameters (side channel collection) with the first 2 principal components, percent variation (cumulative percentage) for each principal component, and eigenvalues for Tres Palacios River and Carancahua Creek.

Principal Component	**Cumulative Percent**	**Eigenvalue**	**TOC Sediment**	**% Solids**	**%Gravel**	**% Silt**	**% Clay**	**% Sand**
PC1	51.9	3.12	-0.295	0.429	-0.169	-0.417	-0.481	0.543
PC2	74.8	1.37	-0.595	-0.100	0.697	-0.323	0.177	-0.119

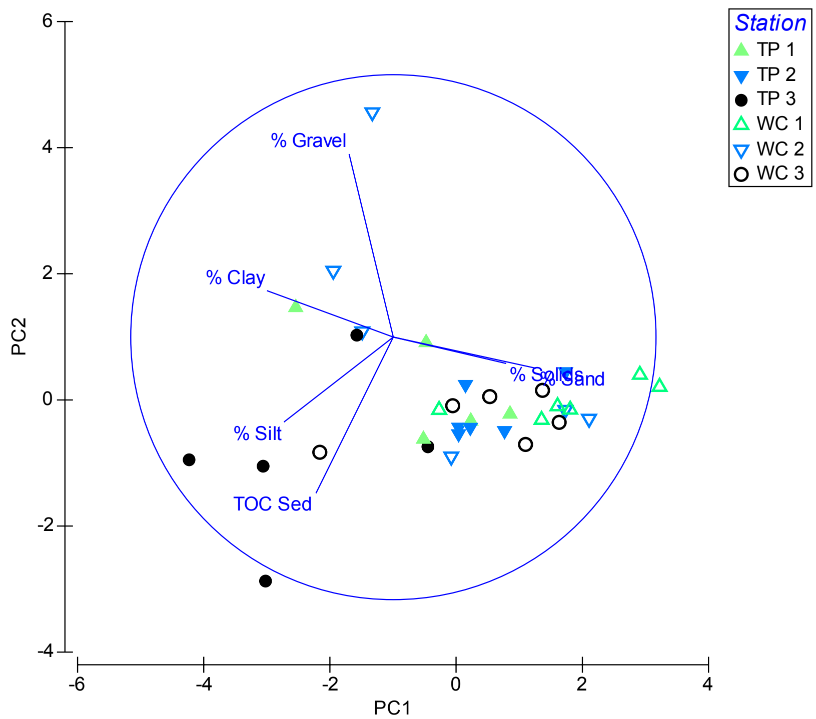


Figure 32. Ordination of the stations based on principal components analysis of sediment parameters (side channel collection) from Tres Palacios River and Carancahua Creek.

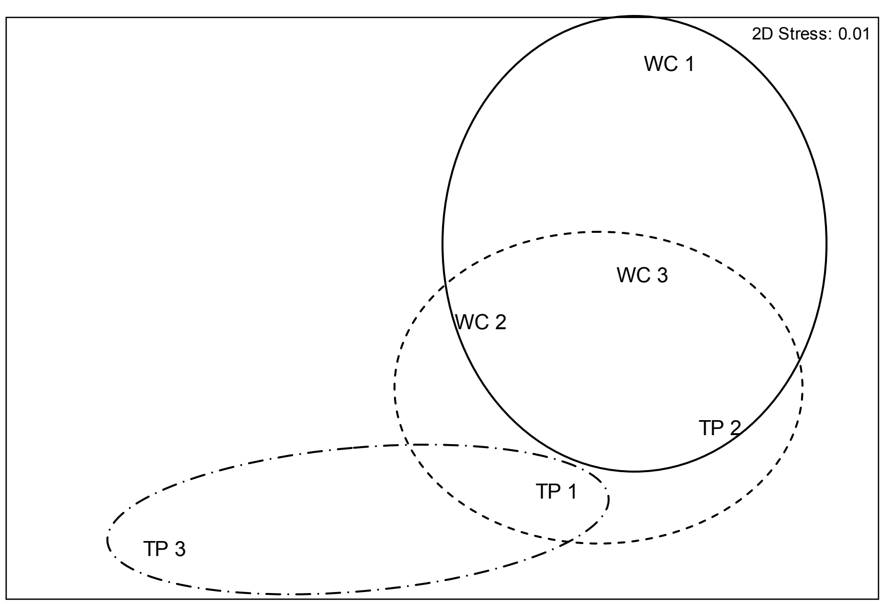


Figure 33. Means plot MDS ordination of the stations based on sediment parameters (side channel collection) taken from Tres Palacios River and Carancahua Creek. Stations within an ellipse are not significantly different based on ANOSIM comparisons ($p > 0.05$).

Table 54. Surface-water quality parameters by station for Garcitas and Carancahua Creeks. Data are means (n=12, unless otherwise noted). Standard deviations are presented in parentheses.

	GC 1	**GC 2**	**GC 3**	**WC 1** [a]	**WC 2** [a]	**WC 3** [a]
BOD	3.08 (0.3)	3.33 (0.9)	3.08 (0.3)	3.10 (0.3)	3.01 (0.3)	3.46 (1.2)
ALK	98.75 (67.3)	85.17 (56.5)	82.83 (45.7)	94.40 (47.1)	97.00 (44.1)	91.73 (40.1)
TSS	31.33 (44.4)	36.25 (67.0)	38.75 (64.5)	31.30 (30.7)	37.46 (32.3)	57.00 (27.8)
VSS	6.25 (5.8)	6.83 (8.1)	6.83 (7.6)	6.80 (3.4)	7.55 (3.9)	11.55 (4.7)
Ammonia	0.08 (0.1)	0.07 (0.1)	0.07 (0.1)	0.07 (0.1)	0.07 (0.1)	0.06 (0.1)
Nitrite	0.08 (0.1)	0.09 (0.1)	0.12 (0.1)	0.06 (0.01)	0.06 (0.1)	0.09 (0.1)
Nitrate	0.09 (0.1)	0.10 (0.1)	0.14 (0.1)	0.37 (0.5)	0.36 (0.5)	0.29 (0.3)
Total N	1.21 (0.4)	1.23 (0.3)	1.17 (0.3)	1.08 (0.2)	1.15 (0.2)	1.38 (0.3)
Phosphorus	0.18 (0.1)	0.17 (0.1)	0.18 (0.1)	0.29 (0.2)	0.27 (0.2)	0.29 (0.1)
TOC	10.17 (4.5)	9.92 (4.9)	8.83 (4.5)	8.30 (1.5)	8.09 (1.4)	7.27 (1.5)
Chloride	910.25 (1538.9)	1516.33 (2341.7)	2249.83 (2931.4)	512.20 (876.6)	667.82 (1002.9)	1584.46 (1862.6)
Sulfate	133.33 (221.2)	217.08 (331.6)	318.17 (414.1)	71.60 (119.1)	93.18 (136.8)	217.9 (258.3)
Fluoride	0.21 (0.2)	0.22 (0.2)	0.26 (0.2)	0.22 (0.1)	0.24 (0.1)	0.26 (0.1)
Chl_a	11.14 (14.6)	7.90 (8.6)	7.26 (6.7)	13.93 (11.8)	12.70 (12.3)	18.76 (27.5)
Pheo_a	10.82 (19.3)	14.28 (31.5)	12.61 (18.4)	8.57 (10.5)	13.8 (17.9)	25.18 (32.2)
TDS	1925.25 (2991.9)	2986.58 (4362.8)	4852.50 (6750.2)	1093.50 (1508.8)	3242.18 (5905.8)	3174.46 (3525.9)
Orthophosphate	0.13 (0.1)	0.15 (0.1)	0.20 (0.2)	0.20 (0.1)	0.19 (0.1)	0.19 (0.1)

[a] n=11, No Water Column Profiles taken during the May 2004 flooding event at WC 1, WC 2, or WC 3.

Table 55. Correlations of the surface water quality measurements with the first 3 principal components, percent variation (cumulative percentage) for each principal component, and eigenvalues for Garcitas and Carancahua Creeks.

	PC 1	**PC 2**	**PC 3**
Cumulative Percent	33.5	48.0	60.2
Eigenvalue	4.69	2.03	1.71
BOD	-0.030	0.505	-0.394
ALK	0.398	-0.087	-0.186
TSS	-0.199	0.318	0.109
Ammonia	-0.125	-0.302	-0.264
Nitrite	0.352	0.209	0.148
Nitrate	0.026	0.360	0.111
Total N	-0.216	0.360	-0.323
Phosphorus	-0.281	0.166	0.394
TOC	-0.395	-0.044	-0.158
Chloride	0.405	0.105	-0.024
Fluoride	0.437	0.052	-0.072
Chl_a	0.027	0.416	-0.014
Pheo_a	0.081	0.032	-0.471
Orthophosphate	0.126	0.162	0.427

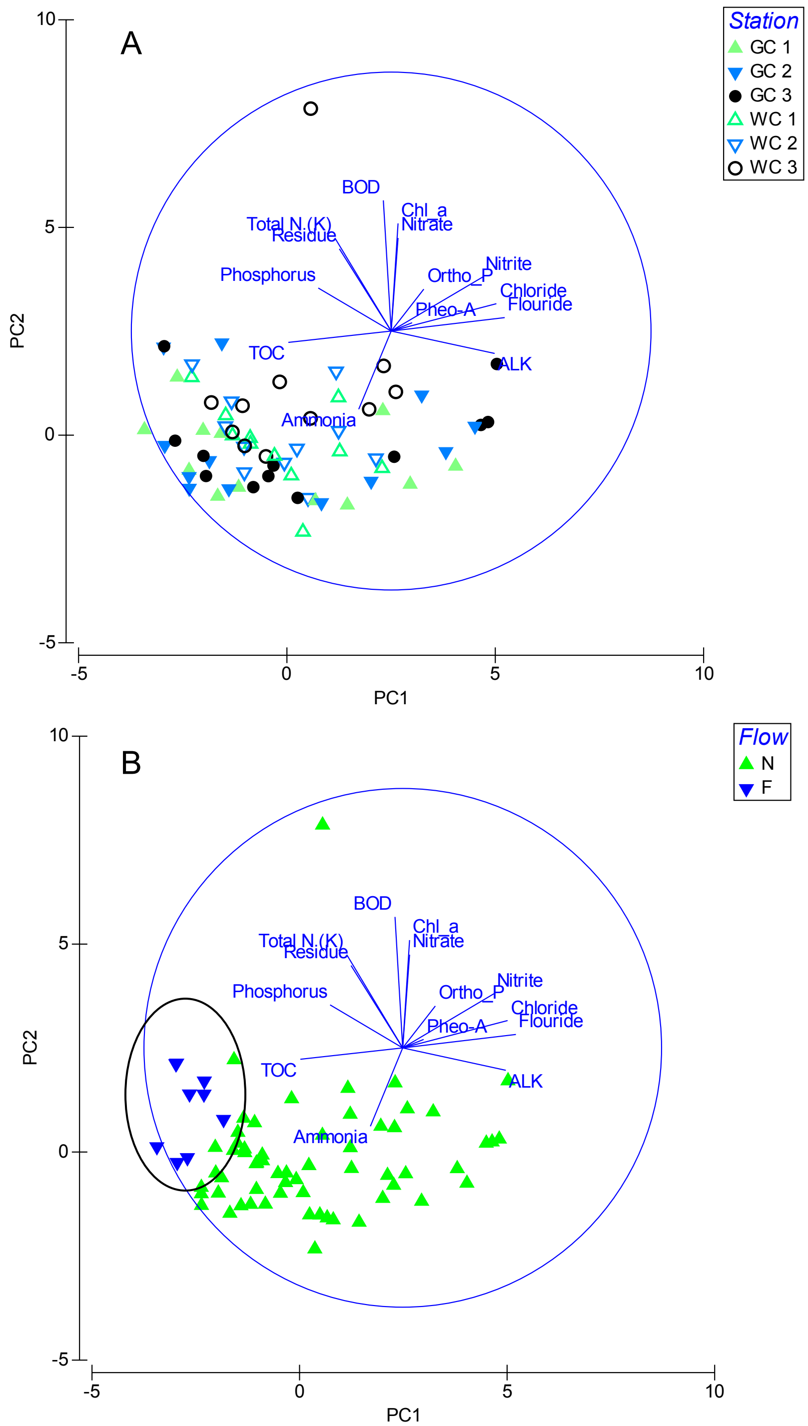
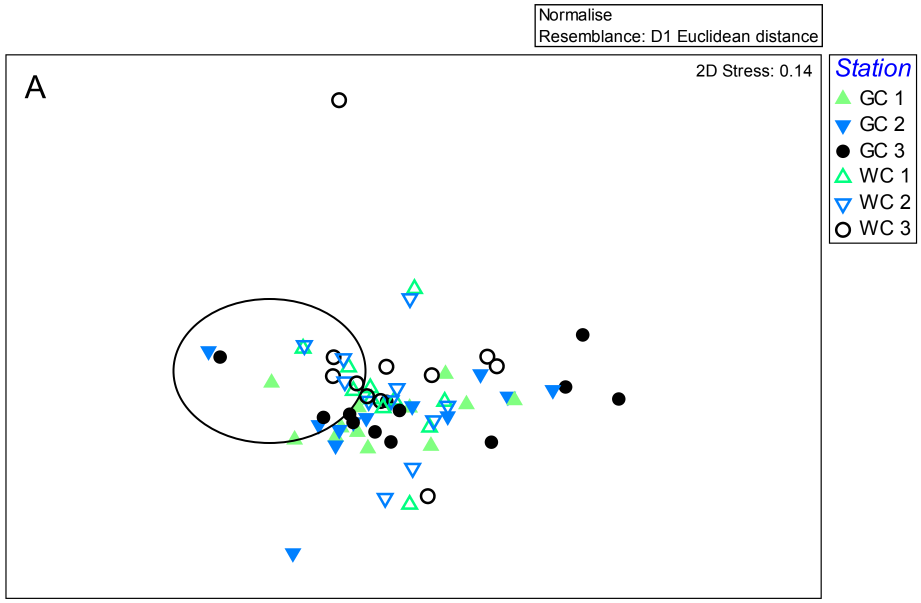


Figure 34. Ordination of the stations based on principal components analysis of surface water quality collections from Garcitas and Carancahua Creeks. A = Stations configuration with vector overlays of the variables used in the analysis; B = Configuration identical to A, but overlaid with designations of flow conditions during sampling events (N = normal flow, F = flooding conditions). Flood samples enclosed within the ellipse.

Global R = -0.113, p = 0.980). Like Tres Palacios, Garcitas Creek also lacked any significant seasonality in surface water quality measurements (Global R = -0.106, p = 0.949). MDS configuration of the stations (rotated to match the pattern seen in the principal components plot of Fig. 34a) is shown in Fig. 35a. Samples from a common stream were pooled and identified as impacted (Garcitas Creek) and control (Carancahua Creek) for an ANOSIM to detect overall differences in surface water quality measurements. No differences in surface water quality were detected between Garcitas or Carancahua Creeks (Global R = 0.006, p = 0.321; see Fig. 35b). Closer inspection of the MDS configurations of these surface water quality measurements reveals consistent gradients that are in agreement with the surface, mid, and bottom-water collections of the routine field parameters (see Tables 39, 40, and 41). Garcitas Creek, or the impacted stream in Fig. 35b, varies primarily along the x-axis, which in this plot is closely related to surface inflow factors (chloride, fluoride, and alkalinity). The field parameters also showed that there was a relatively stronger salinity gradient within Garcitas than was found in Carancahua Creek. The y-axis in Fig. 35b is related to productivity (biological oxygen demand, chlorophyll a, total Kjeldahl nitrogen, and nitrate) and this is the axis that Carancahua most prominently varies across. The strong gradient in dissolved oxygen, both across the stations from the upper to lower segments, as well as within a station from surface saturation to bottom hypoxia, is reinforced by the MDS configurations based on water quality parameters.

Surface and bottom measurements of water quality parameters were related with Spearman's rank correlations, and significant correlations were found within each stream (Garcitas Creek ρ_S = 0.740; *prob*. = 0.001) and Carancahua Creek (ρ_S = 0.699; *prob*. = 0.001). Summary statistics for the bottom water quality measurements are presented in Table 56. Principal component analysis results of bottom water measurements closely matched those of the surface water collections, revealing the importance of inflows (i.e., salinity as measured by positive loadings of chloride, fluoride, and alkalinity) and the influx of nutrients into each stream (total Kjeldahl nitrogen, biological oxygen demand, and residue (TSS)) as the factors configuring the stations within the space defined by the first two principal components (Fig. 36).

Summary statistics of the sediment parameters from the middle of Garcitas and Carancahua Creeks are presented in Table 57. The first two principal components explained 93.6 % of the variance (Table 58) and separated samples on the basis of percent sand or clay (component one) and the presence of gravel (component two; see Fig. 37). While explaining only 4.5 % of the total variation, principal component three (not shown in Fig. 37) was important in that percent silt (correlation of 0.835) and percent solids (correlation of 0.392) values recorded at the lower-most station on Carancahua Creek were identified as being significantly different from all other stations. This result is best visualized in the means plot of the stations presented in Fig. 38. The upper and middle stations on Garcitas Creek are clearly different from all the others; based on their very



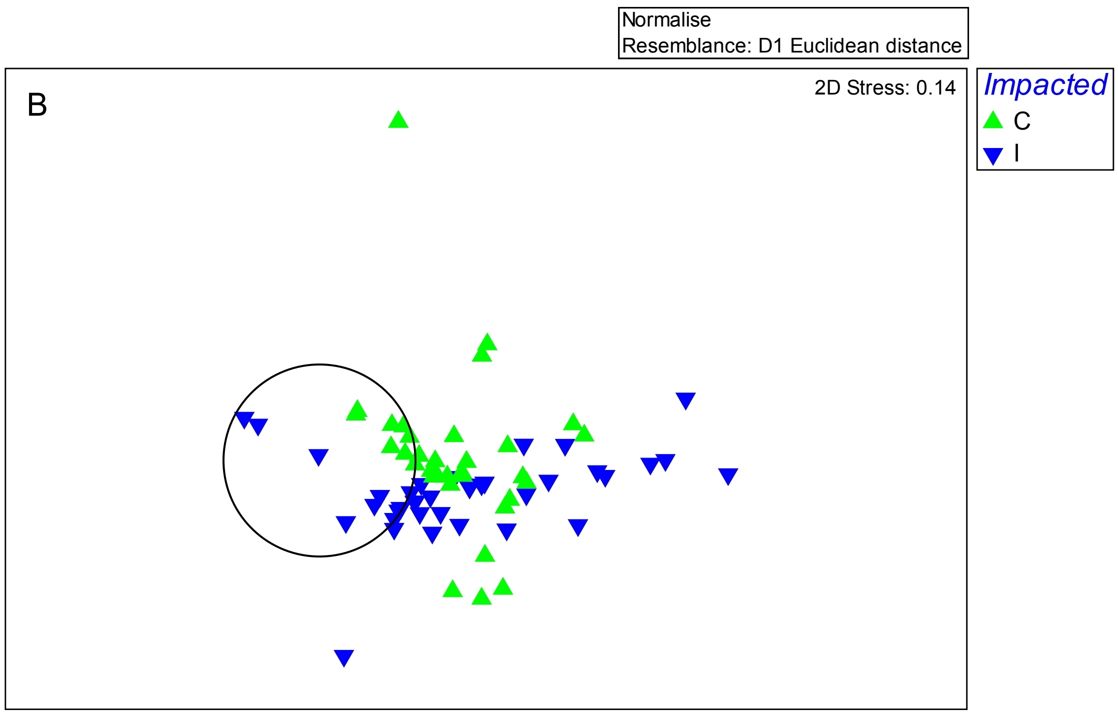


Figure 35. A = MDS configurations of stations based on surface water quality measurements. Flood samples enclosed within the ellipse; B = Identical configuration as A, but overlaid with designations of level of Impact (Impacted stream I = Garcitas Creek, Control stream C = Carancahua Creek).

Table 56. Bottom-water quality parameters by station for Garcitas and Carancahua Creeks. Data are means (n=12, unless otherwise noted). Standard deviations are presented in parentheses.

	GC 1 [a]	GC 2 [a]	GC 3 [a]	WC 1 [a]	WC 2 [a]	WC 3 [a]
BOD	3.00 (0.0)	3.00 (0.0)	3.00 (0.0)	3.01 (0.3)	3.00 (0.00)	3.55 (1.5)
ALK	103.91 (64.3)	91.00 (50.2)	93.00 (37.4)	97.64 (47.8)	95.55 (42.9)	92.27 (40.5)
TSS	23.64 (9.7)	24.27 (12.2)	40.82 (36.1)	91.46 (154.9)	45.91 (30.8)	178.82 (243.7)
VSS	5.18 (1.5)	5.18 (2.4)	6.73 (4.2)	12.00 (16.1)	7.18 (3.4)	28.55 (41.6)
Ammonia	0.09 (0.1)	0.09 (0.1)	0.10 (0.1)	0.26 (0.2)	0.17 (0.1)	0.06 (0.1)
Nitrite	0.95 (0.1)	0.15 (0.1)	0.24 (0.2)	0.08 (0.1)	0.07 (0.1)	0.11 (0.1)
Nitrate	0.95 (0.1)	0.14 (0.1)	0.21 (0.2)	0.39 (0.6)	0.37 (0.5)	0.28 (0.3)
Total N	1.45 (0.3)	1.14 (0.3)	1.16 (0.2)	1.48 (0.6)	1.32 (0.3)	1.48 (0.4)
Phosphorus	0.17 (0.1)	0.18 (0.1)	0.16 (0.1)	0.35 (0.2)	0.31 (0.2)	0.32 (0.1)
TOC	9.82 (4.7)	9.55 (5.3)	7.64 (4.9)	8.09 (1.9)	7.91 (1.7)	7.09 (1.4)
Chloride	1008.64 (1762.0)	2005.18 (2660.8)	3341.82 (3052.3)	953.91 (1342.2)	933.55 (1203.4)	1683.46 (1921.1)
Sulfate	163.82 (248.8))	285.91 (374.3)	471.18 (431.9)	131.18 (181.7)	128.64 (163.7)	231.91 (267.2)
Fluoride	0.24 (0.2)	0.25 (0.2)	0.34 (0.2)	0.23 (0.1)	0.24 (0.1)	0.28 (0.2)
TDS	2262.73 (3213.9)	3833.82 (4878.7)	6277.00 (5553.7)	1952.18 (2428.7)	1876.00 (2144.2)	3325.09 (3649.3)
Orthophosphate	0.51 (0.1)	0.24 (0.2)	0.37 (0.3)	0.23 (0.1)	0.22 (0.1)	0.22 (0.1)

[a] n=11, Bottom Water Quality samples not taken during the May 2004 flooding event.

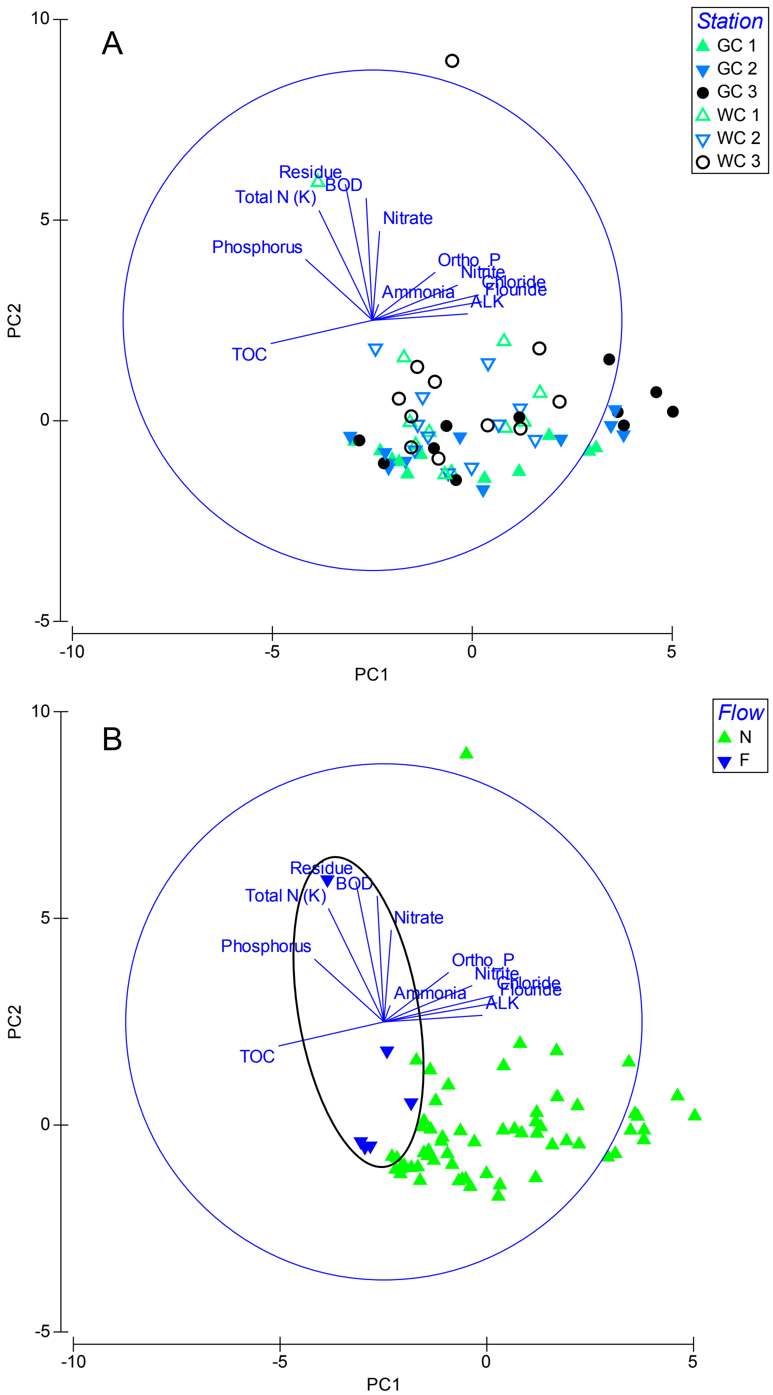


Figure 36. Ordination of the stations based on principal components analysis of bottom water quality collections from Garcitas and Carancahua Creeks. A = Stations configuration with vector overlays of the variables used in the analysis (vectors have been shifted from the graph origin to aid in interpretation); B = Configuration identical to A, but overlaid with designations of flow conditions during sampling events (N = normal flow, F = flooding conditions). Flood samples enclosed within the ellipse.

Table 57. Sediment parameters (mid-channel) by station for Garcitas and Carancahua Creeks. Data are means (n=6, unless otherwise noted). Standard deviations are presented in parentheses. Entries with a dash (-) are less than 0.01 %.

	GC 1 [a]	GC 2 [a]	GC 3	WC 1	WC 2	WC 3
TOC Sed	4140.00 (313.1)	4080.00 (178.9)	7450.00 (4995.1)	11767.67 (7776.1)	8445.00 (5290.9)	15860.00 (4118.1)
% Solids	75.79 (5.8)	75.76 (6.5)	56.56 (20.00)	51.43 (22.7)	58.30 (19.0)	36.64 (10.9)
% Gravel	-	0.30 (0.7)	-	0.51 (1.2)	-	-
% Silt	1.24 (1.6)	0.89 (1.0)	10.47 (15.6)	12.87 (13.8)	3.73 (6.6)	17.05 (2.8)
% Clay	3.67 (3.7)	3.60 (2.5)	24.62 (25.9)	39.96 (29.2)	23.15 (23.5)	64.66 (17.0)
% Sand	95.29 (3.3)	95.30 (2.2)	64.90 (41.1)	46.51 (40.9)	73.19 (29.0)	18.62 (17.8)

[a] n=5, Samples not processed, arrived at lab with containers broken.

Table 58. Correlations of the sediment parameters (mid-channel) with the first 2 principal components, percent variation (cumulative percentage) for each principal component, and eigenvalues for Garcitas and Carancahua Creeks.

Principal Component	Cumulative Percent	Eigenvalue	TOC Sediment	% Solids	%Gravel	% Silt	% Clay	% Sand
PC1	77.5	4.65	-0.453	0.440	-0.119	-0.408	-0.456	0.461
PC2	93.6	0.97	0.045	0.003	0.977	-0.181	-0.059	0.080

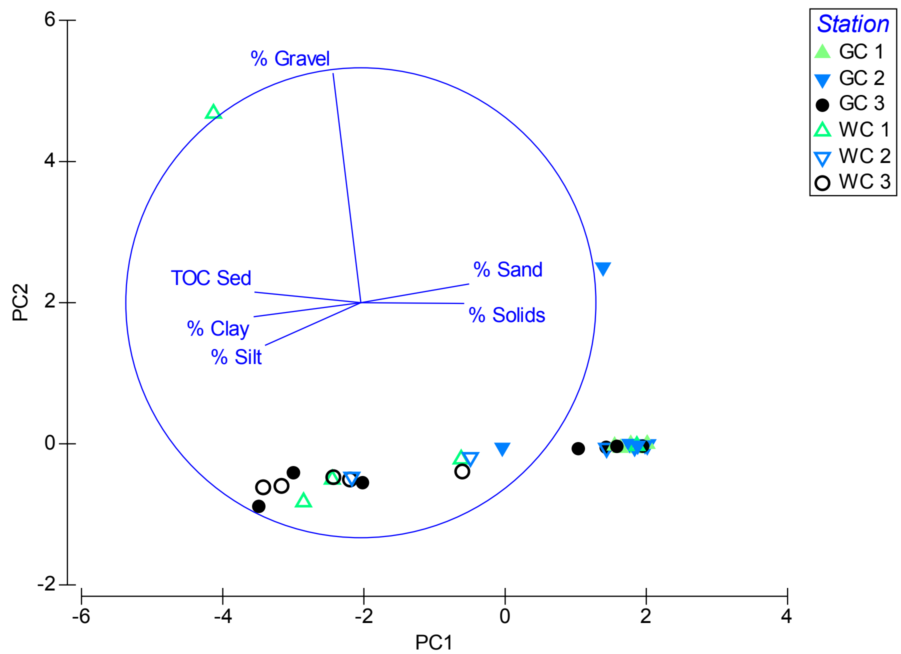


Figure 37. Ordination of the stations based on principal components analysis of sediment parameters (mid-channel) from Garcitas and Carancahua Creeks.

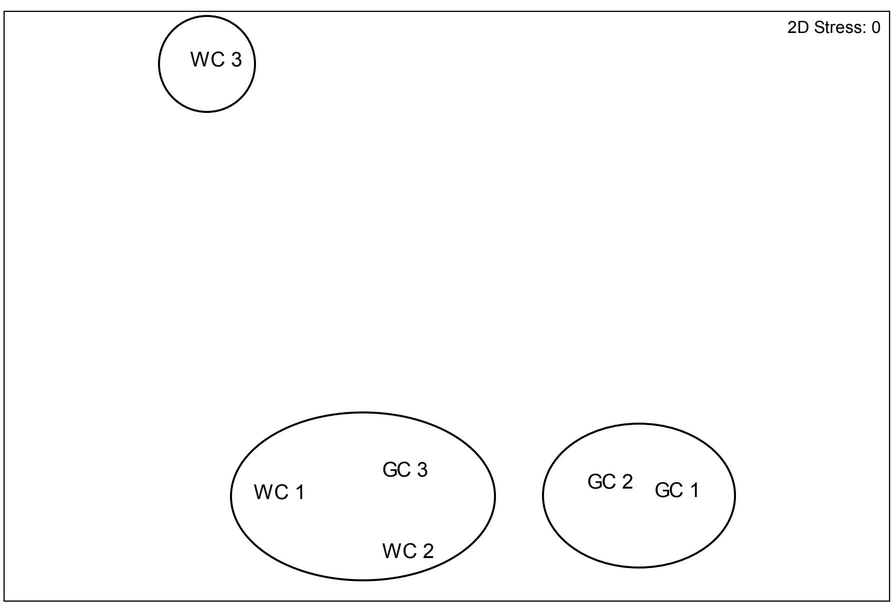


Figure 38. Means plot MDS ordination of the stations based on sediment parameters (mid-channel) taken from Garcitas and Carancahua Creeks. Stations within an ellipse are not significantly different based on ANOSIM comparisons ($p > 0.05$).

high percent sand composition in the middle sediments (the x-axis in Fig. 37 represents the gradient of clays to sands, from left to right). The lower station on Garcitas Creek (GC 3) is similar to the upper and middle stations on Carancahua, with decreasing sand and increasing clays found in these sediments. The y-axis in Fig. 38 now describes the third principal component (the second principal component shown in Fig. 37 is rotated towards the reader in Fig. 38, and now lies perpendicular to the page) with increasing values of total organic carbon and percent silt best separating the lower-most station on Carancahua Creek from all the others (compare the means plot configurations in Fig. 38 to Table 57).

Summary statistics for the side channel collections from Garcitas and Carancahua Creeks are presented in Table 59. The first two principal components explain 80.0% of the variation (Table 60), and again separate the stations based on their percentages of sands and silts or clays. Unlike the comparisons involving Tres Palacios, the percent sand values found in Garcitas side sediments were actually lower than those found for its middle samples. However, Carancahua Creek still had more fine sediments present at all sampling stations when compared to Garcitas.

ANOSIM results of the side sediments were consistent with the pattern from the mid-channel collections, in that the upper and middle stations on Garcitas Creek (GC 1 and GC 2) were significantly different from the lower station (GC 3), and the lower station on Garcitas Creek had sediment composition much more like those found throughout the reference stream (increased total organic carbon, increased percent clay and silt, combined with a decrease in sand content; Fig. 39). Side sediments from the middle station on Carancahua Creek were highly variable during this study, with the composition ranging from quite firm with low organic content to very soft with an abundance of silt and clay and increased organics. Gravel content of the side sediments, while still quite variable, was found at the highest proportions of any of the sampling stations here at the middle location of the reference stream. This station showed the greatest amount of variability within the space defined by the first two principal components (especially along the y-axis; Fig. 40).

Biological Sampling

Nekton Collections – Tres Palacios and Carancahua Creek

Bag Seines

The twelve sampling trips conducted over the two years of this study resulted in 36 bag seine collection opportunities. A total of 5,855 fishes, representing at

Table 59. Sediment parameters (side channel collection) by station for Garcitas and Carancahua Creeks. Data are means (n=6, unless otherwise noted). Standard deviations are presented in parentheses. Entries with a dash (-) are less than 0.01 %.

	GC 1	GC 2	GC 3	WC 1	WC 2	WC 3
TOC Sed	6626.67 (5130.6)	4000.00 (0.0)	5346.67 (1124.9)	4598.65 (2550.1)	5672.97 (3545.3)	6724.14 (4211.4)
% Solids	66.98 (10.6)	69.73 (9.6)	64.98 (9.1)	68.42 (5.9)	61.18 (10.5)	64.13 (10.6)
% Gravel	0.14 (0.3)	-	0.45 (1.1)	-	7.45 (9.6)	-
% Silt	8.78 (7.3)	5.94 (10.7)	18.00 (3.8)	13.67 (9.9)	21.68 (9.2)	23.71 (8.7)
% Clay	11.95 (11.0)	10.03 (10.3)	19.09 (9.5)	16.81 (6.2)	25.62 (11.2)	23.09 (10.9)
% Sand	79.14 (17.9)	84.23 (20.9)	62.46 (12.2)	69.36 (15.5)	45.26 (22.0)	53.19 (18.1)

Table 60. Correlations of the sediment parameters (side channel collection) with the first 2 principal components, percent variation (cumulative percentage) for each principal component, and eigenvalues for Garcitas and Carancahua Creeks.

Principal Component	Cumulative Percent	Eigenvalue	TOC Sediment	% Solids	%Gravel	% Silt	% Clay	% Sand
PC1	60.4	3.63	-0.290	0.386	-0.256	-0.445	-0.491	0.512
PC2	80.0	1.17	-0.586	-0.180	0.727	-0.301	0.058	-0.039

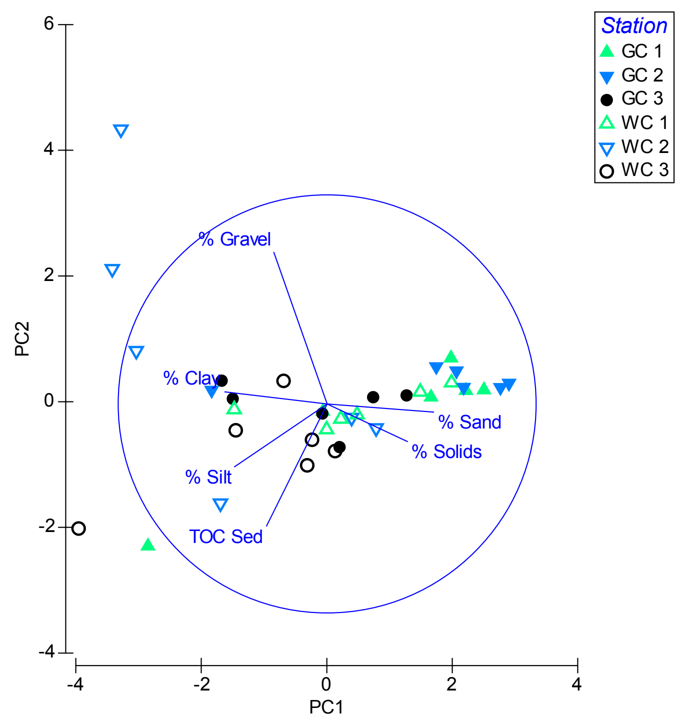


Figure 39. Ordination of the stations based on principal components analysis of sediment parameters (side channel collection) from Garcitas and Carancahua Creeks.

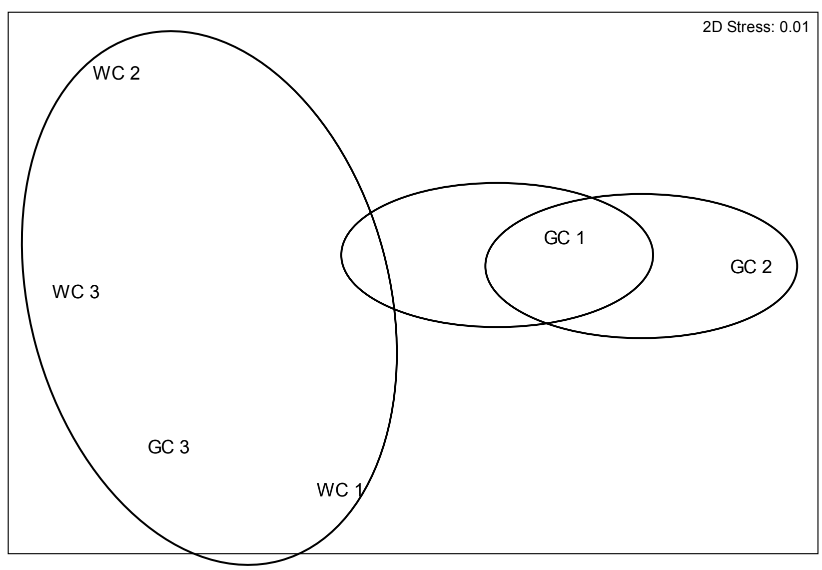


Figure 40. Means plot MDS ordination of the stations based on sediment parameters (side channel collection) taken from Garcitas and Carancahua Creeks. Stations within an ellipse are not significantly different based on ANOSIM comparisons ($p > 0.05$).

least 48 different species from 25 families were collected from Tres Palacios. Additionally, 5,085 invertebrates from 10 species were also collected. Numerically, three species accounted for > 90 % of the total number of individuals (gulf menhaden 77.3 %, bay anchovy 10.9 %, and white shrimp 3.1 %). A complete taxonomic list of fishes, with total numbers of individuals collected from each stream, is given in Appendix 6 (nektonic invertebrates are listed in Appendix 7). Far more individuals were collected with the bag seines on Carancahua Creek. A total of 39,036 fishes, representing 41 different species from 20 families, were collected on Carancahua Creek. A total of 3,373 invertebrates from 10 species were also recorded. Despite the vast difference in the numbers of individuals collected between the two streams, the relative proportion of the dominant taxa was virtually identical. Gulf menhaden (77.8 % of the catch), bay anchovy (10.6 % of the catch), and white shrimp (3.4 % of the catch) made up > 90 % of the total bag seine collections within Carancahua Creek.

MDS configurations of the bag seine collections are shown in Fig. 41. The greatest degree of separation, across both study streams, involves the nekton community compositions found at the lower-most stations. While stations 1 and 2 (upper and middle stations on each stream) are generally well mixed amongst each other in the MDS space, station 3 (the lower station on each stream) forms the most cohesive grouping along the bottom of the MDS plot. Flooding event samples are also identified within Fig. 41, and unlike the water quality measurements, flooding events were less important in structuring the biological community as measured with the bag seines. ANOSIM results confirmed the differences amongst the stations within both Tres Palacios (Global R = 0.203; *prob*. = 0.001) and Carancahua Creek (Global R = 0.189; *prob*. = 0.003). In each case, the lower station was identified as the station with the significantly different nekton community (Fig. 42).

The upper and middle stations across both streams were then pooled together and compared to the lower stations from both streams, and the species responsible for any significant differences were identified with SIMPER analysis (Table 61). While gulf menhaden made up the majority of the catch within both station groups, they tended to be more abundant in the fresher station of the Upper group on both streams. Marine species (including numerous invertebrates) were more abundant at the lower stations. These species included white shrimp, grass shrimp, brown shrimp, blue crabs, sand seatrout, Atlantic croaker, and spot. Bay anchovy were evenly distributed throught the entire reach of both study streams. Freshwater species that far were more abundant in the upper stations included western mosquitofish, prawns (Family Macrobranchium), bluegills, and the sailfin molly.

Seasonality was also an important factor in the bag seine collections, as can be seen in Fig. 43a (ANOSIM Global R = 0.399; *prob*. = 0.001 for Tres Palacios and Global R = 0.537; *prob*. = 0.001 for Carancahua Creek). Spring and fall

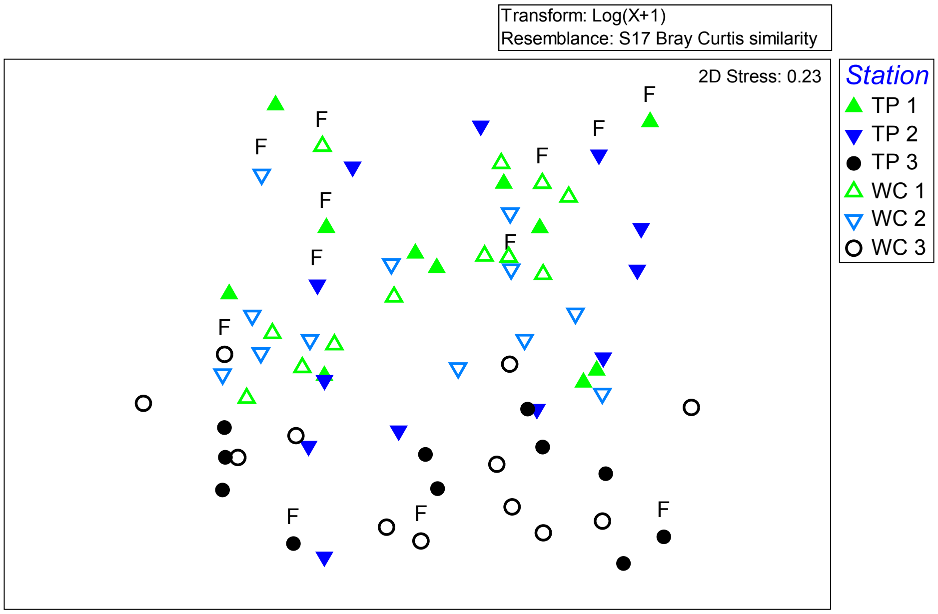


Figure 41. MDS configuration of the stations based on bag seine collections from Tres Palacios and Carancahua Creek. Flood samples identified (F).

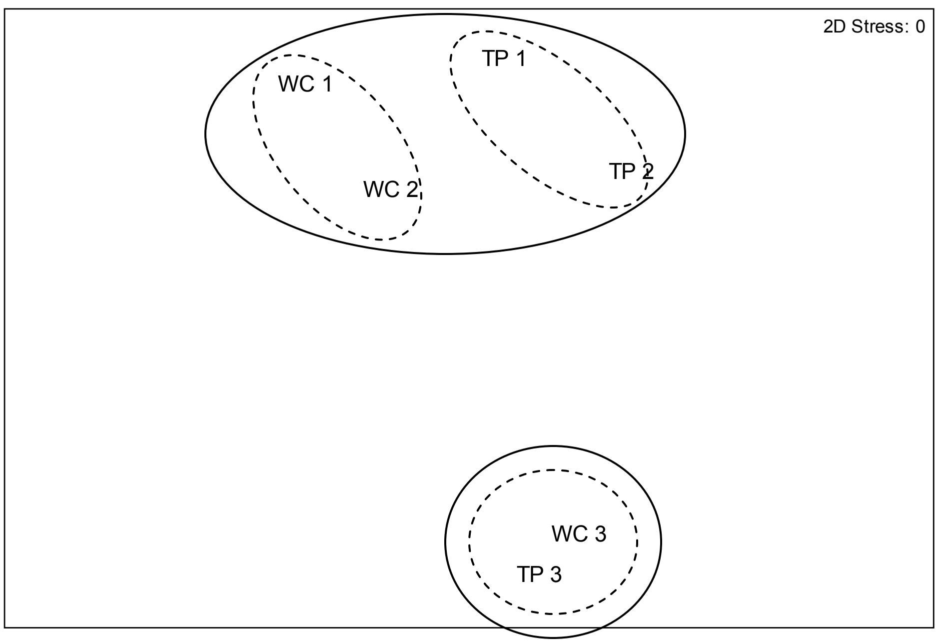


Figure 42. Means plot MDS ordination of the stations based on bag seine collections from Tres Palacios and Carancahua Creeks. Stations within an ellipse (dashed lines represent within stream comparisons; solid lines across stream comparisons) are not significantly different (ANOSIM $p > 0.05$).

Table 61. The contributions of selected individual species to the total average dissimilarity between fish assemblages as measured by bag seines found in the upper and middle (Group U) and lower (Group L) stations on Tres Palacios and Carancahua Creeks. Average abundance (Av. Abund), as measured by number per 20 m shoreline; percent contribution (%) to the average dissimilarity; and the ratio ($\delta avg_{(i)}$ / SD $_{(\delta i)}$) are listed for each species. Species are listed order of relative contribution to the total dissimilarity.

Species	Group U Av.Abund	Group L Av.Abund	%	Ratio
White shrimp	10.43	69.85	9.53	0.97
Gulf menhaden	393.40	116.49	9.20	0.95
Bay anchovy	51.33	57.55	9.14	1.27
Western mosquitofish	10.58	0.07	8.38	1.62
Grass shrimp	7.76	27.70	7.86	1.17
Brown shrimp	5.06	36.22	5.83	0.75
Blue crab	1.04	3.44	4.64	1.32
Blue catfish	1.82	1.01	3.36	0.90
Striped mullet	4.34	0.99	3.02	0.77
Sand seatrout	0.10	2.31	3.00	0.80
Tidewater silverside	1.42	1.07	2.61	0.84
Atlantic croaker	1.64	9.16	2.60	0.62
Spot	1.96	6.72	2.58	0.60
Hogchoker	1.51	0.42	2.47	0.81
Family Macrobrachium	4.37	0.47	2.33	0.51
Sailfin molly	1.12	0.04	2.08	0.69
Pink shrimp	-	2.35	1.48	0.36
Family Unionidae	0.94	0.17	1.39	0.42
Naked goby	0.36	0.16	1.30	0.61
Southern flounder	0.45	0.13	1.25	0.71
Silver perch	-	1.24	1.14	0.41
Mojarra sp.	0.31	0.15	1.13	0.63
Pinfish	0.18	0.44	1.10	0.70
Bluegill	0.31	0.00	0.96	0.49
Ladyfish	0.34	0.14	0.95	0.56
Red drum	0.03	0.28	0.94	0.57
Total Percent Dissimilarity			64.96	

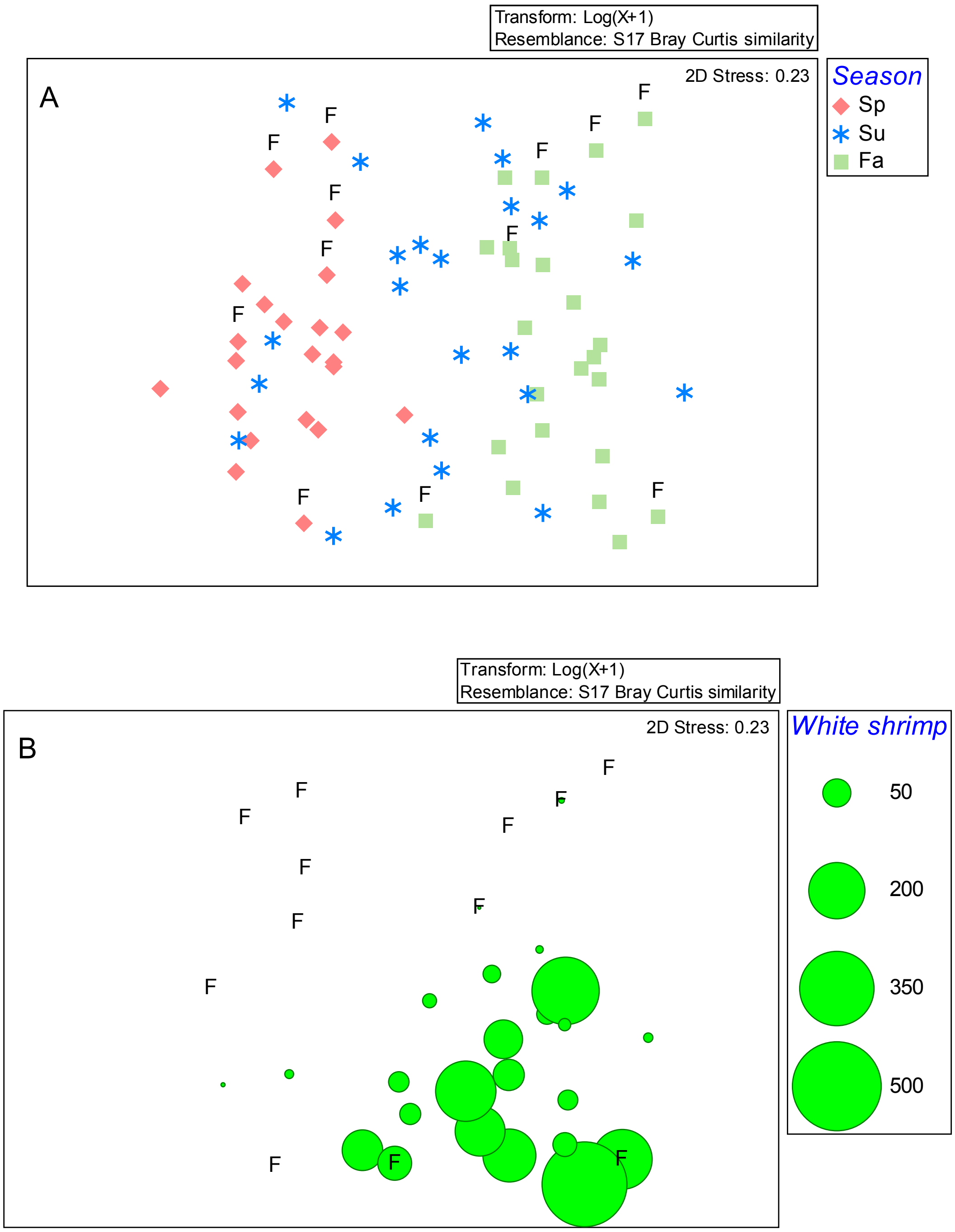


Figure 43. MDS configuration of the stations based on bag seine collections from Tres Palacios and Carancahua Creek. Station configuration based on Fig. 41, but overlaid onto each station are: A = season of collection, and B = white shrimp CPUE. Size of each circle is represented by the scale at the right. Flooding condition sampling events are designated by F in each Figure.

collections had distinct nekton communities, with the summer nekton communities spanning the two seasons. SIMPER results of the seasonality factor are presented in Table 62. White shrimp CPUE is presented as an example of this seasonality (Fig. 43b), with white shrimp found primarily in the lower stations only during the summer and fall seasons.

Trawls

Total numbers in the trawl collections were more evenly distributed between Tres Palacios and Carancahua Creek, as 33,688 fishes representing 33 species were collected from Tres Palacios and 40,403 fishes from 28 species from Carancahua Creek. Invertebrates were numerically more abundant on Tres Palacios (2,154 individuals from 9 species as compared to 373 individuals from 8 species from Carancahua Creek). Similar to the bag seines, gulf menhaden, bay anchovy, and white shrimp dominated the trawl collections on Tres Palacios, accounted for > 90 % of the total number of individuals. The relative proportion of finfish was less skewed in the trawls, with gulf menhaden comprising 44.1 % of the catch and bay anchovy making up 43.4 % of the catch. White shrimp abundance was similar to the bag seines, accounting for an additional 4.5 % of the total. On Carancahua Creek, gulf menhaden (48.2 % of the catch), bay anchovy (46.4 % of the catch), and Atlantic croaker (3.1 % of the catch) made up the majority of the trawl collections. White shrimp accounted for less than 1 % of the trawl catch on Carancahua Creek.

MDS configurations of the trawl collections are shown in Fig. 44. While the greatest degree of separation among the stations within Tres Palacios still involved the nekton community compositions found at the lower-most station (Global R = 0.236; *prob*. = 0.004; station 3 is different from both 1 and 2), no differences were detected in the trawl collections within Carancahua Creek (Global R = -0.047; *prob*. = 0.735; see means plot MDS of Fig. 45). The nekton communities at the lower-most station on Carancahua Creek tended to range across the vertical MDS space of Fig. 44, showing overall community composition more like the upper and middle stations, depending on the season of collection. The flooding event samples were more of a cohesive group with the trawls than was the case with the bag seines, with most of these samples falling out in the upper portions of the MDS space.

The upper and middle stations on Tres Palacios were then pooled together with all the collections from Carancahua Creek and compared to the lower station, and the species responsible for any significant differences were identified with SIMPER analysis (Table 63). Despite the trawls sampling a very different portion of the stream, (bag seines sampled the shallow-water fringes while the trawls sampled the middle of the stream bottom) many of the same species identified from the bag seine analysis were also important discriminating species in the trawl collections. The abundance of gulf menhaden and bay anchovies were

Table 62. Comparisons of the fish assemblages collected seasonally with bag seines during spring (Sp), summer (Su) and fall (Fa) on Tres Palacios and Carancahua Creeks. Percent contribution (%) to the average dissimilarity; and the ratio ($\delta avg_{(i)}$ / SD $_{(\delta i)}$) are listed for each species. A dashed line (-) represents no species contribution to the comparison.

	Sp vs. Su		Sp vs. F		Su vs. F	
Species	**%**	**Ratio**	**%**	**Ratio**	**%**	**Ratio**
Gulf menhaden	16.90	1.52	18.26	2.16	10.37	0.90
Bay anchovy	8.87	1.30	8.85	1.21	9.30	1.19
White shrimp	2.54	0.49	8.78	1.01	9.34	0.95
Grass shrimp	6.90	1.24	6.59	1.44	6.88	1.06
Brown shrimp	6.51	0.89	4.95	0.75	3.83	0.57
Atlantic croaker	5.95	1.14	5.43	1.16	-	-
Western mosquitofish	5.66	1.07	3.65	0.99	5.20	1.09
Spot	4.99	0.95	4.23	0.88	1.09	0.40
Striped mullet	4.92	0.94	3.26	0.71	3.16	0.94
Tidewater silverside	3.35	1.00	1.85	0.72	3.76	0.98
Blue catfish	2.86	0.98	3.66	1.02	4.68	1.17
Family Unionidae	2.79	0.58	-	-	3.11	0.64
Sailfin molly	2.43	0.75	1.94	0.74	3.20	0.94
Family Macrobrachium	2.39	0.64	3.50	0.74	3.04	0.51
Blue crab	2.24	1.09	3.13	1.14	3.82	1.16
Southern flounder	2.22	0.95	1.58	0.81	1.32	0.62
Hogchoker	1.96	0.88	3.43	1.00	4.15	1.14
Ladyfish	1.85	0.86	1.27	0.65	1.11	0.62
Pinfish	1.42	0.83	0.95	0.68	0.71	0.45
Sand seatrout	1.40	0.57	-	-	1.89	0.67
Naked goby	-	-	1.46	0.65	1.81	0.62
Lepomis sp.	1.37	0.46	1.43	0.72	1.64	0.55
Mojarra sp.	1.02	0.54	1.14	0.75	1.84	0.90
Total Percent Dissimilarity	65.38		74.73		64.78	

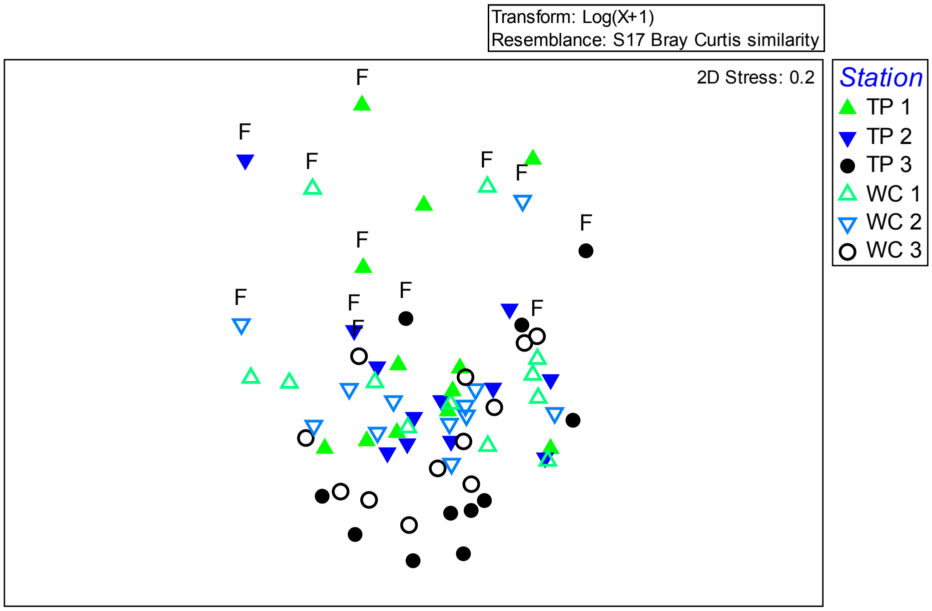


Figure 44. MDS configuration of the stations based on trawl collections from Tres Palacios and Carancahua Creek. Flood samples identified (F).

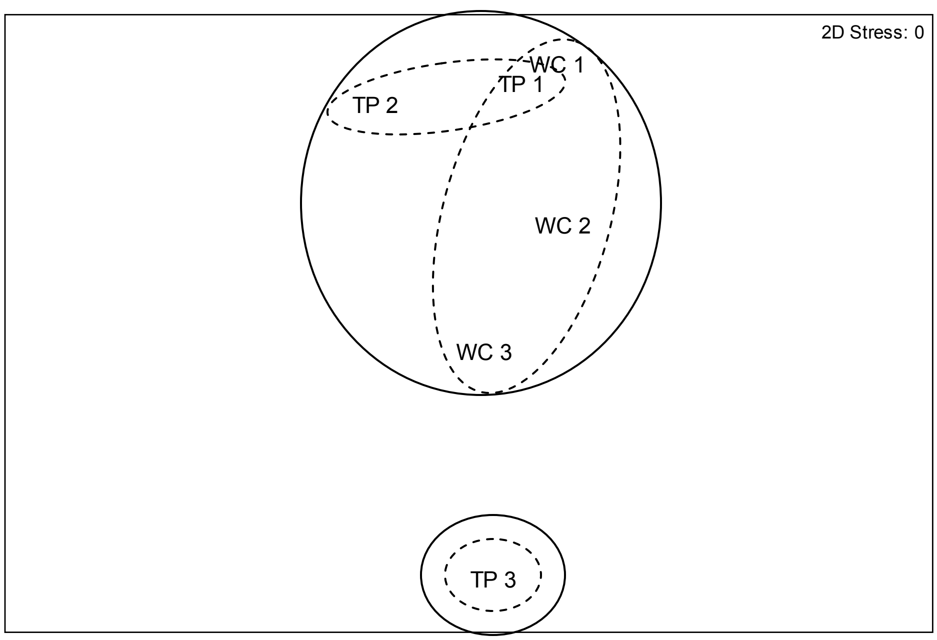


Figure 45. Means plot MDS ordination of the stations based on trawl collections from Tres Palacios and Carancahua Creeks. Stations within an ellipse (dashed lines represent within stream comparisons; solid lines across stream comparisons) are not significantly different (ANOSIM $p > 0.05$).

Table 63. The contributions of selected individual species to the total average dissimilarity between fish assemblages as measured by trawls in the upper and middle (Group U) and lower (Group L) stations on Tres Palacios and Carancahua Creeks. Average abundance (Av. Abund), as measured by catch per hour; percent contribution (%) to the average dissimilarity; and the ratio ($\delta avg_{(i)}$ / SD $_{(\delta i)}$) are listed for each species. Species are listed order of relative contribution to the total dissimilarity.

Species	Group U Av.Abund	Group L Av.Abund	%	Ratio
Bay anchovy	1934.64	2017.83	12.55	0.96
Gulf menhaden	2351.77	1457.83	11.40	1.11
White shrimp	0.96	328.61	10.42	1.14
Blue catfish	20.31	69.57	8.98	1.07
Sand seatrout	3.62	73.57	6.38	0.92
Blue crab	1.75	13.04	5.68	1.02
Atlantic croaker	74.04	394.35	5.00	0.65
Brown shrimp	0.79	72.17	4.00	0.72
Hogchoker	0.25	8.00	3.96	0.92
Family Macrobrachium	2.58	4.70	3.10	0.60
Spot	0.80	16.52	2.83	0.53
Grass shrimp	0.92	3.13	2.51	0.60
Hardhead catfish	-	2.96	1.91	0.63
Silver perch	-	8.61	1.82	0.48
Spotted seatrout	-	1.48	1.77	0.53
Spotted gar	0.37	1.57	1.41	0.44
Red drum	0.08	2.96	1.28	0.32
Black drum	-	2.61	1.08	0.28
Striped mullet	0.58	0.35	1.00	0.36
Bay whiff	-	1.04	0.97	0.44
Southern flounder	-	0.70	0.93	0.34
Blackcheek tonguefish	-	1.39	0.85	0.37
Total Percent Dissimilarity			58.32	

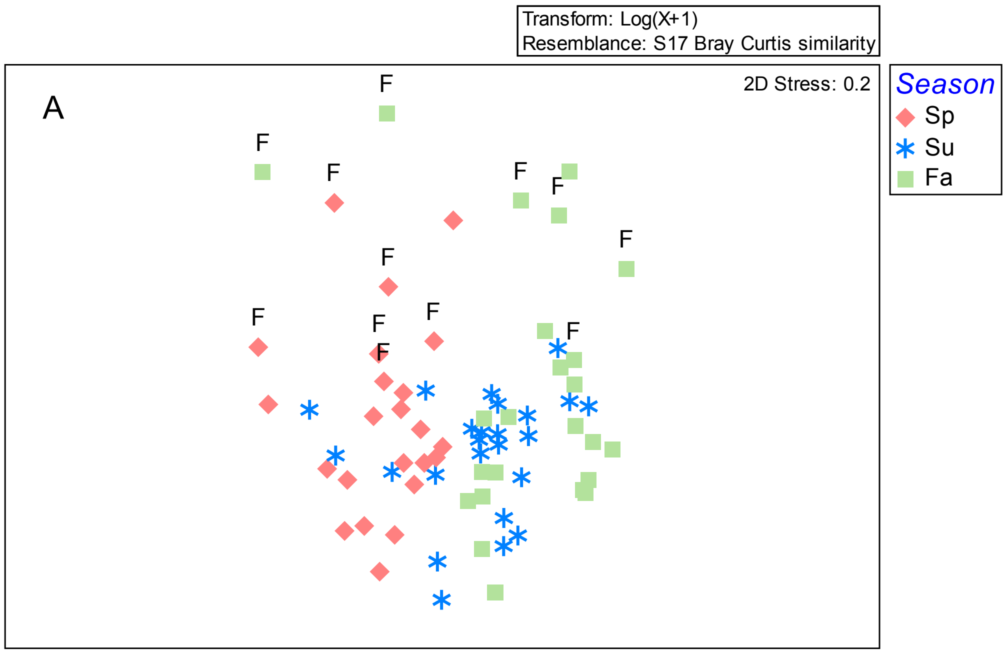
more equally represented in the nekton by the trawl, and similar to the pattern seen with the bag seines, these species were distributed throughout the entire tidal reach on both streams. Marine finfishes, particularily those in the family Sciaenidae, dominated the community dissimilarities as measured by trawl collections. Scieanids such as sand seatrout, Atlantic croaker, spot, red drum, and black drum were far more abundant at the lower-most station. Freshwater taxa (such as Macrobrachium, blue catfish, and spotted gar) were not well represented in the trawl collections, and were all collected in higher abundance in the lower stations (Table 63). Only gulf menhaden and striped mullet, both marine forms, had higher abundance values in the upper stations.

Seasonality was evident in the trawl collections, as can be seen in Fig. 46a (ANOSIM Global R = 0.203; *prob*. = 0.006 for Tres Palacios and Global R = 0.228; *prob*. = 0.003 for Carancahua Creek). Spring and fall collections had distinct nekton communities, while the summer collections spanned across the two seasons. SIMPER results of this seasonality factor are presented in Table 64. Atlantic croaker CPUE (the species with the highest ratio values for the comparisons involving spring vs. summer and spring vs. fall) is shown as an example of trawl-based seasonality, with this species collected primarily in the lower stations during the spring and summer seasons (Fig. 46b).

Gill Nets

Gill nets were the least effective gear, in terms of total number of individuals collected. Only 856 fishes representing 31 species were collected from Tres Palacios, while 774 fishes from 28 species were found on Carancahua Creek. Invertebrates were particularly underrepresented in the gill nets (only 12 blue crabs were collected on Tres Palacios, while 2 blue crabs comprised the complete invertebrate collection from Carancahua Creek). Overall, the gill nets recorded a very different nektonic community, dominated in each tidal stream by hardhead catfish, spotted gar, gizzard shad, smallmouth buffalo, and blue catfish. Gulf menhaden comprising only a small fraction of the gill net catches (6.3 % on Tres Palacios and 2.3 % on Carancahua Creek). Because of the small size of bay anchovies and the relatively large size of the mesh used in the gill nets, bay anchovies were essentially absent from the gill nets.

MDS configurations of the gill net collections are shown in Fig. 47. No consistent differences in the nekton communities are evident within either tidal stream (Tres Palacios Global R = 0.112; *prob*. = 0.115; Carancahua Creek Global R = 0.160; *prob*. = 0.064; see means plot MDS of Fig. 48). The sample size for gill nets is quite small for the lower-most station of Carancahua Creek (only n = 6), as many of the overnight net sets on were compromised by alligator activity. Additionally, flooding event samples from all the stations on Carancahua Creek are missing from one of the spring season replicates in 2004.



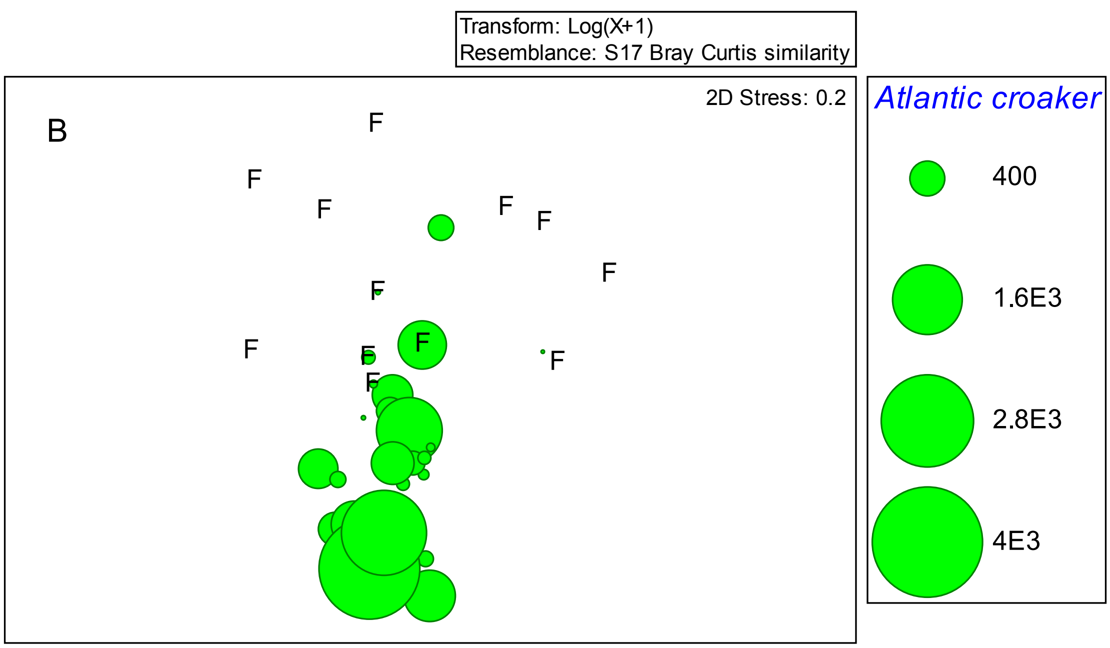


Figure 46. MDS configuration of the stations based on trawl collections from Tres Palacios and Carancahua Creek. Station configuration based on Fig. 44, but overlaid onto each station are: A = season of collection, and B = Atlantic croaker CPUE. Size of each circle is represented by the scale at the right. Flooding condition sampling events are designated by F in each Figure.

Table 64. Comparisons of the fish assemblages collected seasonally with bag seines during spring (Sp), summer (Su) and fall (Fa) on Tres Palacios and Carancahua Creeks. Percent contribution (%) to the average dissimilarity; and the ratio ($\delta avg_{(i)}$ / SD $_{(\delta i)}$) are listed for each species. A dashed line (-) represents no species contribution to the comparison.

	Sp vs. Su		Sp vs. F		Su vs. F	
Species	**%**	**Ratio**	**%**	**Ratio**	**%**	**Ratio**
Bay anchovy	19.17	1.12	18.59	1.06	21.22	0.97
Gulf menhaden	16.07	1.16	20.78	1.36	25.47	1.17
Atlantic croaker	15.51	1.60	15.90	1.72	2.12	0.43
Blue catfish	9.06	1.18	8.54	1.02	11.11	1.22
Sand seatrout	5.31	0.81	1.13	0.37	6.17	0.82
Blue crab	3.72	0.73	1.94	0.47	4.06	0.74
Family Macrobrachium	3.47	0.50	4.55	0.65	2.50	0.50
Spot	3.25	0.72	3.10	0.70	-	-
Brown shrimp	2.88	0.61	2.35	0.54	1.31	0.38
White shrimp	2.65	0.52	2.65	0.59	3.44	0.58
Grass shrimp	2.34	0.60	2.42	0.59	2.73	0.62
Hogchoker	1.71	0.46	1.98	0.46	1.09	0.44
Striped mullet	1.37	0.34	1.15	0.34	2.54	0.44
Ladyfish	1.24	0.39	0.92	0.32	-	-
Spotted gar	1.10	0.39	0.81	0.36	1.34	0.42
Family Penaeidae	1.00	0.23	1.01	0.23	-	-
Gizzard shad	0.85	0.32	1.00	0.32	2.06	0.46
Naked goby	-	-	1.01	0.42	1.02	0.39
Bluegill	-	-	-	-	0.91	0.31
Silver perch	-	-	-	-	0.81	0.31
Red drum	-	-	-	-	0.80	0.32
Longnose gar	-	-	0.80	0.31	-	-
Total Percent Dissimilarity	56.46		71.02		56.16	

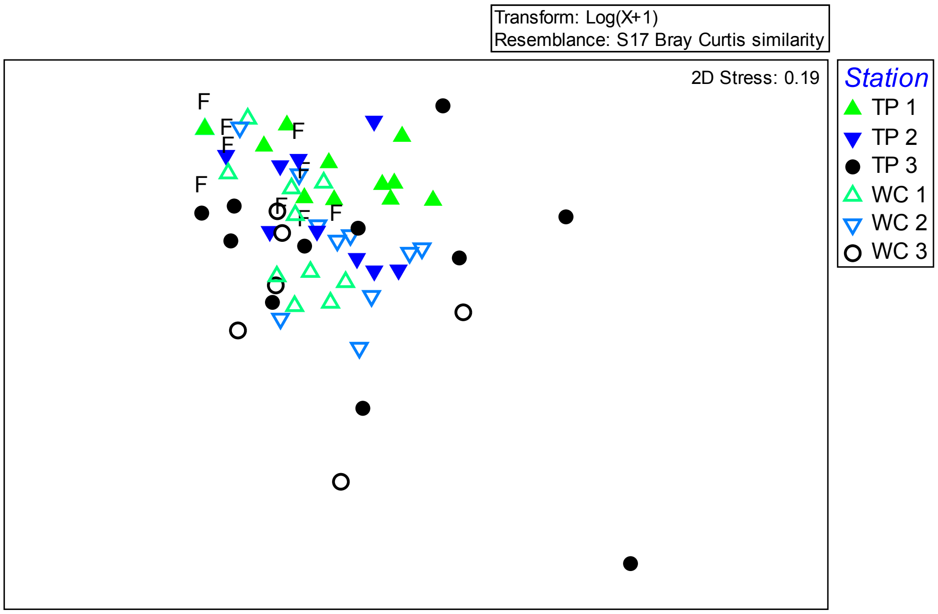


Figure 47. MDS configuration of the stations based on gill net collections from Tres Palacios and Carancahua Creek. Flood samples identified (F).

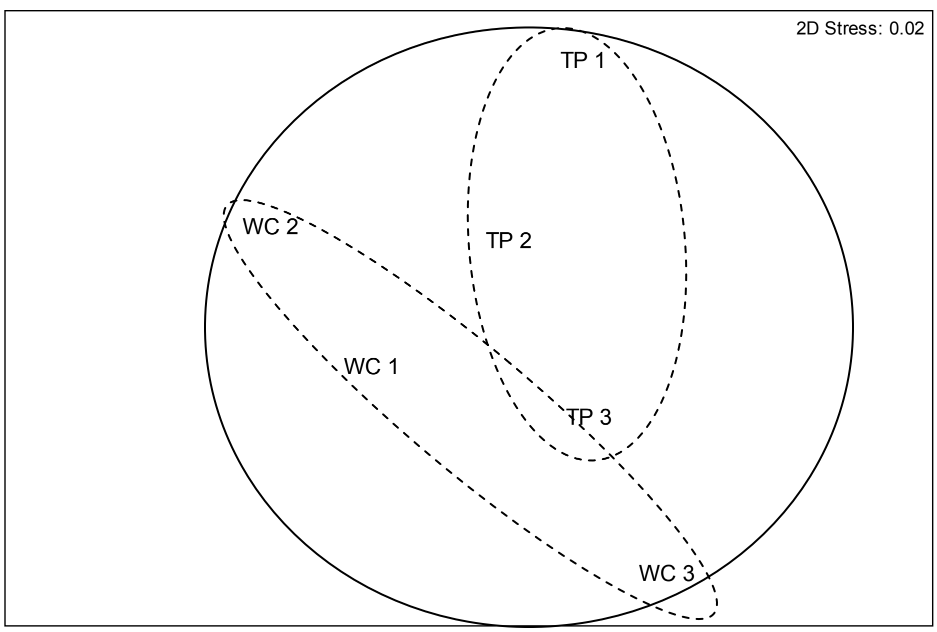


Figure 48. Means plot MDS ordination of the stations based on gill net collections from Tres Palacios and Carancahua Creeks. Stations within an ellipse (dashed lines represent within stream comparisons; solid lines across stream comparisons) are not significantly different (ANOSIM $p > 0.05$).

All stations within each stream were then pooled and tested with an ANOSIM for overall differences in gill net based communities (Tres Palacios = Impacted, Carancahua Creek = Control). No significant differences were found between the two streams (Global R = 0.042; *prob*. = 0.068). While no significant differences were found within or between the two streams, SIMPER analysis can still be used to describe the overall community structure (Table 65). As measured by gill nets, the overall communities were quite similar between the two streams (compare the total percent dissimilarity value of 42.89 found with the gill nets to those found with the bag seines (64.96) and trawls (58.32); see Tables 61 and 63). While the bag seine and trawls communities were dominated by marine forms, gill net catches had a much higher percentage of freshwater fish (e.g., spotted gar, gizzard shad, blue catfish, and smallmouth buffalo).

While seasonality was not evident in the gill net collections from Tres Palacios (Global R = 0.092; *prob*. = 0.136), the spring and fall seasons had different communities within Carancahua Creek (spring vs. fall R = 0.501; *prob*. = 0.008; see Fig. 48a). During the fall season, abundance of spotted gar, smallmouth buffalo, red drum, and hardhead catfish were significantly lower than during the spring season. An example of the overall lack of gill net based seasonality is shown in Fig. 48b, with gizzard shad (the third-most abundant species recorded with this gear) collected in similar abundance levels across all seasons from each stream.

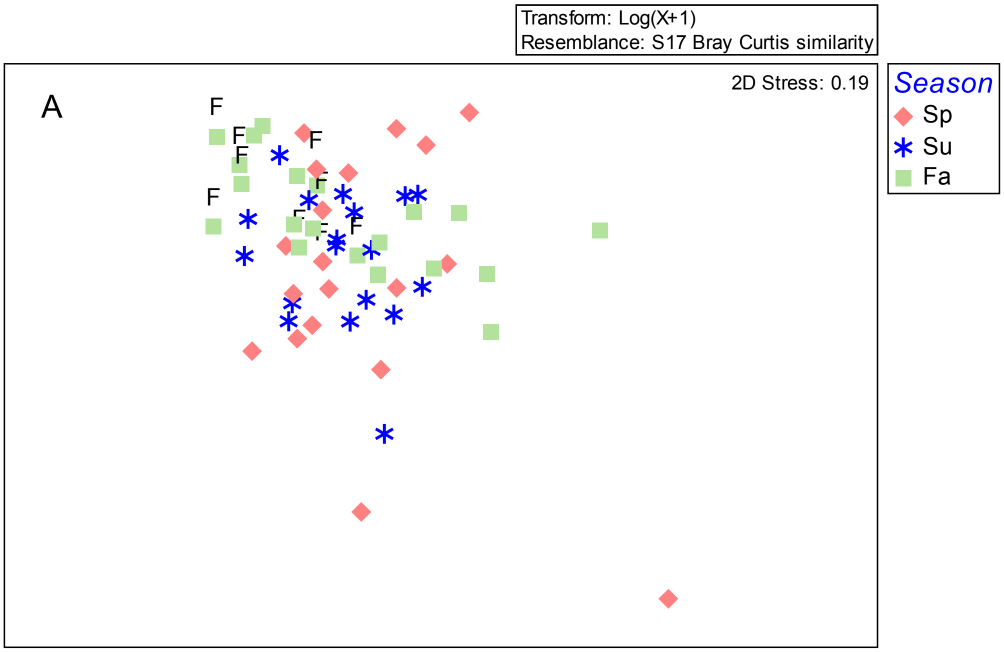
Nekton Collections – Garcitas and Carancahua Creek

Bag Seines

A total of 38,896 finfish (48 species from 21 families) and 2,868 invertebrates (9 species) were collected with bag seine from Garcitas Creek. The majority of the individuals were quite similar in proportion to Carancahua Creek, with Gulf menhaden (77.9 % of the total catch), bay anchovy (10.6 % of the total catch), and white shrimp (3.1 % of the total catch) making up > 90 % of the collection. MDS configurations of the bag seine collections are shown in Fig. 50. A greater degree of overlap of nekton community compositions were found at Garcitas Creek, with stations 1 and 2 (upper and middle stations) having similar communities (pairwise ANOSIM R = 0.067; *prob*. = 0.273), and stations 2 and 3 (middle and lower stations) also sharing a number of species (pairwise ANOSIM R = 0.038; *prob*. = 0.366, see Fig. 51). Across the streams, the overlap of the middle station on Garcitas is evident, with less uniqueness attributable to the lower-most stations. Like the comparisons involving Tres Palacios, flooding events were less important in structuring the biological community as measured with the bag seines.

Table 65. The contributions of selected individual species to the total average dissimilarity between fish assemblages as measured by gill nets in the Impacted (Tres Palacios = Group I) and Control (Carancahua Creek = Group C) stream. Average abundance (Av. Abund), as measured by number per hour; percent contribution (%) to the average dissimilarity; and the ratio ($\delta avg_{(i)}$ / SD $_{(\delta i)}$) are listed for each species. Species are listed order of relative contribution to the total dissimilarity.

Species	**Group I Av.Abund**	**Group C Av.Abund**	**%**	**Ratio**
Spotted gar	0.158	0.463	16.31	1.24
Gizzard shad	0.269	0.328	13.07	1.26
Blue catfish	0.238	0.181	10.49	1.00
Smallmouth buffalo	0.157	0.189	9.51	1.06
Red drum	0.076	0.189	8.88	1.06
Hardhead catfish	0.453	0.230	8.31	0.45
Gulf menhaden	0.129	0.046	6.18	0.64
Longnose gar	0.094	0.027	5.24	0.75
Striped mullet	0.059	0.066	4.17	0.57
Black drum	0.029	0.014	1.77	0.62
Gafftopsail catfish	0.071	0.006	1.72	0.31
Blue crab	0.028	0.006	1.59	0.56
Silver perch	0.032	-	1.32	0.38
Ladyfish	0.023	0.011	1.24	0.30
Bull shark	0.012	0.012	1.05	0.39
Total Percent Dissimilarity			42.89	



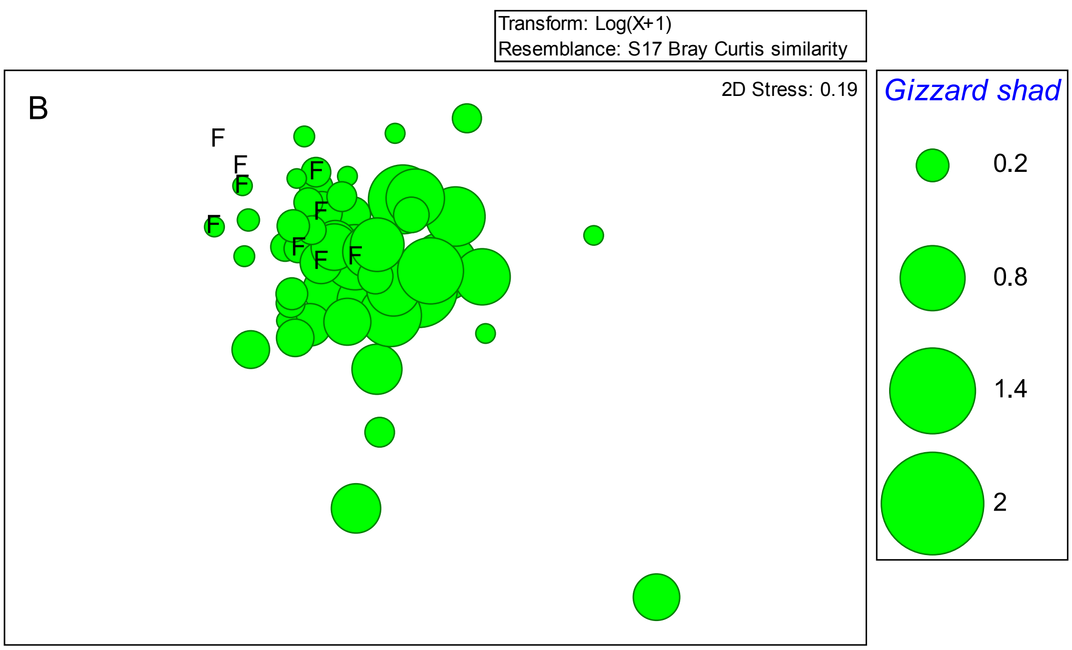


Figure 49. MDS configuration of the stations based on gill net collections from Tres Palacios and Carancahua Creek. Station configuration based on Fig. 47, but overlaid onto each station are: A = season of collection, and B = gizzard shad CPUE. Size of each circle is represented by the scale at the right. Flooding condition sampling events are designated by F in each Figure.

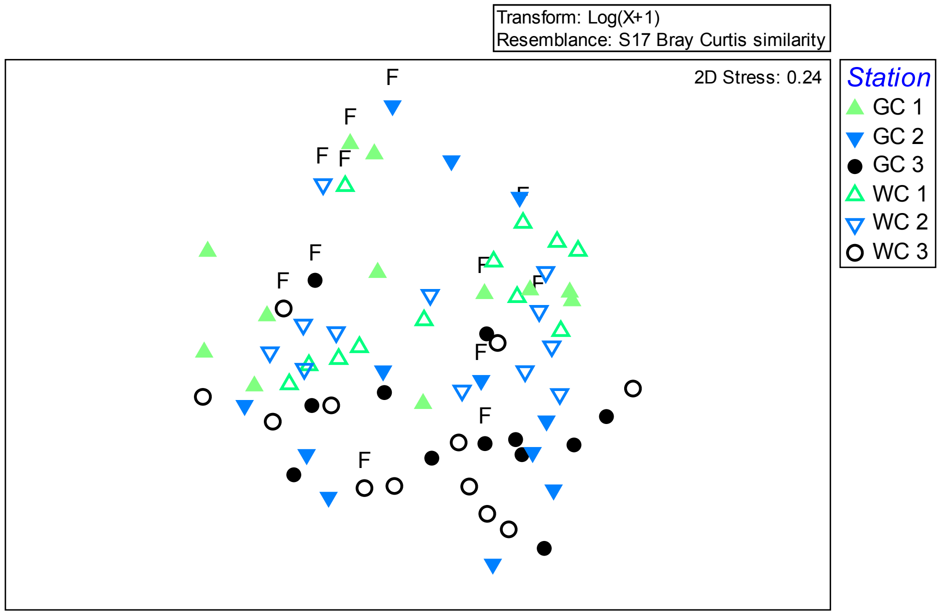


Figure 50. MDS configuration of the stations based on bag seine collections from Garcitas and Carancahua Creeks. Flood samples identified (F).

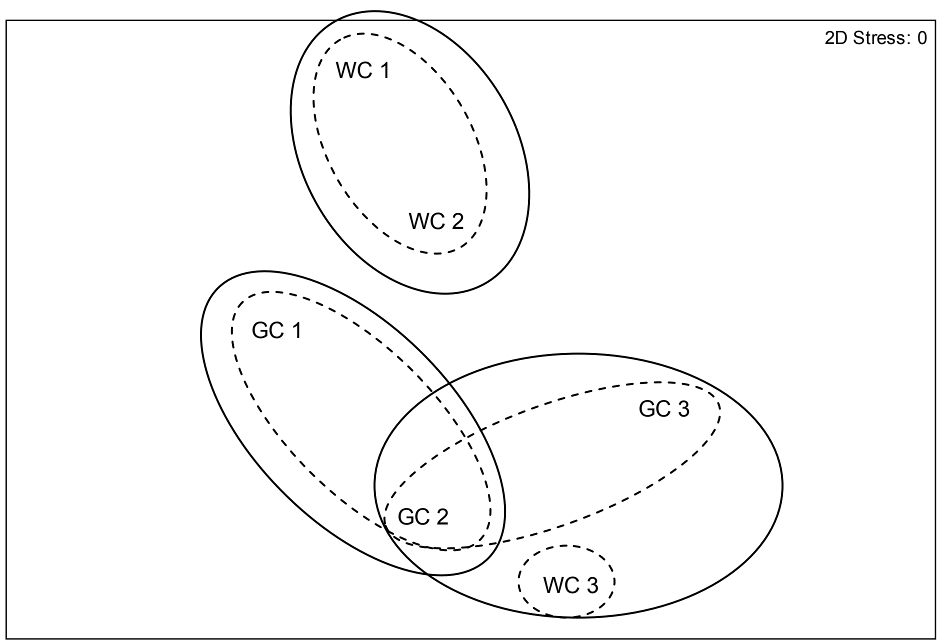


Figure 51. Means plot MDS ordination of the stations based on bag seine collections from Garcitas and Carancahua Creeks. Stations within an ellipse (dashed lines represent within stream comparisons; solid lines across stream comparisons) are not significantly different (ANOSIM *p* > 0.05).

Because of the higher degree of community overlap seen on Garcitas Creek, SIMPER analysis was utilized to identify the species responsible for the station ordination seen in Fig. 51 (Table 66). While many marine forms that typically were found in highest abundance at the lowest stations (much like the comparisons involving Tres Palacios), these same species were routinely found at the middle station on Garcitas Creek (% contribution values in Table 66 greatly increasing in the station 2 vs. station 3 comparison). These species included brown shrimp, bay whiff, grass shrimp, and the mojarras. By contrast, spot were found in similar abundance levels at all three station on Garcitas Creek, and its % contribution value is equal among the three comparisons. Species overlapping between the upper and middle station included some freshwater forms (sailfin molly and gizzard shad) as well as some marine forms (gulf menhaden and striped mullet). Based on the average dissimilarity value between stations 2 and 3, it is clear there was a high degree of overlap in the species making up the community composition at these two stations (Table 66).

Seasonality was an important factor in the bag seine collections, as can be seen in Fig. 52a (ANOSIM Global R = 0.372; *prob*. = 0.002 for Garcitas Creek and Global R = 0.537; *prob*. = 0.001 for Carancahua Creek). Spring and fall collections had distinct nekton communities, with the summer nekton communities spanning the two seasons. Spring collections were dominated by gulf menhaden, grass shrimp, brown shrimp, spot, and Atlantic croaker, while fall collections were characterized by bay anchovy, white shrimp, sailfin molly, blue crab, and hogchokers (Table 67). Summer collections were characterized by species spanning across multiple seasons, such as gulf menhaden, bay anchovy, white shrimp, brown shrimp, and western mosquitofish. Fig. 52b presents an example of one the species whose abundance spanned across multiple seasons. Not only were tidewater silversides collected from all seasons, they were also found at all stations on each tidal stream.

Trawls

Trawl collections on Garcitas Creek were generally lower than those on Carancahua Creek in both total numbers (24,278 fishes from Garcitas vs. 40.403 fishes from Carancahua) and species richness (21 finfish species from Garcitas vs. 28 species from Carancahua). Invertebrates were also less abundant in the impacted stream (102 individuals from 8 species from Garcitas) as compared to the control stream (343 individuals from 8 species from Carancahua). The relative proportion of the trawl catch was slightly different on Garcitas Creek, with bay anchovy making up the largest percentage of the total (61.1 %). Gulf menhaden were still an important component of the nekton within this stream (36.1 % of the total catch), with Atlantic croaker comprising an additional 3.0 % of the catch. Overall, invertebrates made up a very small proportion of the trawl collection on Garcitas Creek (white shrimp accounted for less than 0.1 % of the

Table 66. Comparisons of the fish assemblages collected from each station (1 = upper, 2 = middle, and 3 = lower) with bag seines on Garcitas Creek. Percent contribution (%) to the average dissimilarity; and the ratio ($\delta avg_{(i)}$ / SD $_{(\delta i)}$) are listed for each species. A dashed line (-) represents no species contribution to the comparison.

	1 vs. 2		1 vs. 3		2 vs. 3	
Species	**%**	**Ratio**	**%**	**Ratio**	**%**	**Ratio**
Gulf menhaden	13.56	1.02	13.53	1.04	9.99	0.99
Bay anchovy	9.63	1.31	10.14	1.19	11.52	1.33
White shrimp	7.23	0.87	8.16	1.06	9.93	1.19
Sailfin molly	6.76	1.18	6.26	0.90	3.54	1.06
Western mosquitofish	6.33	1.51	6.93	1.53	1.38	0.75
Spot	4.46	0.88	4.03	0.80	4.63	0.81
Striped mullet	4.42	0.95	4.20	0.97	2.97	1.01
Atlantic croaker	3.37	1.04	2.71	0.86	3.20	0.81
Blue crab	3.20	1.27	3.22	1.29	4.06	1.42
Brown shrimp	2.75	0.63	4.04	0.74	5.36	0.78
Blue catfish	2.63	0.70	2.21	0.67	2.11	0.69
Tidewater silverside	2.63	1.29	2.95	0.93	3.40	1.09
Pinfish	2.49	0.92	2.49	0.98	3.15	0.98
Gulf killifish	2.41	0.58	0.85	0.68	2.67	0.57
Bay whiff	2.23	0.69	2.00	0.63	3.26	0.73
Saltmarsh topminnow	2.19	0.85	1.27	0.61	1.66	0.63
Grass shrimp	2.12	0.56	6.02	0.97	7.13	1.05
Gizzard shad	1.98	0.52	0.99	0.49	1.20	0.30
Sheepshead minnow	1.67	0.63	-	-	-	-
Mojarra species	1.65	0.71	1.40	0.36	2.84	0.66
Hogchoker	1.51	0.81	1.12	0.72	1.14	0.60
Naked goby	1.47	0.75	-	-	1.33	0.68
Southern flounder	1.23	0.87	0.87	0.64	1.20	0.91
Largemouth bass	0.98	0.64	-	-	-	-
Family Unionidae	-	-	1.61	0.63	1.65	0.61
Sheepshead minnow	-	-	1.45	0.53	-	-
Ladyfish	0.93	0.46	-	-	-	-
Golden topminnow	0.90	0.49	0.88	0.49	-	-
Atlantic leatherjacket	-	-	-	-	1.01	0.57
Total Percent Dissimilarity	72.67		74.44		68.15	

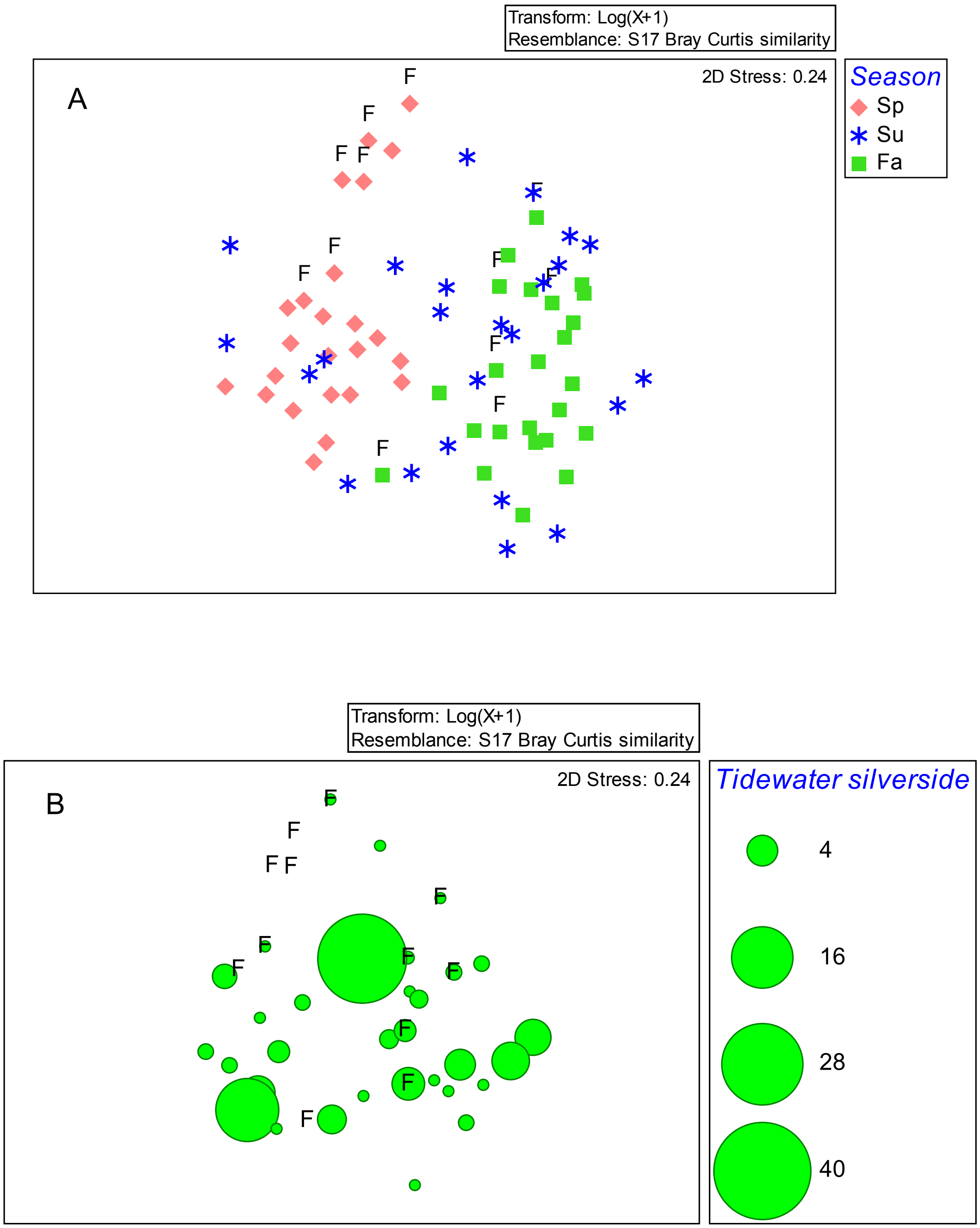


Figure 52. MDS configuration of the stations based on bag seine collections from Garcitas and Carancahua Creeks. Station configuration based on Fig. 50, but overlaid onto each station are: A = season of collection, and B = tidewater silverside CPUE. Size of each circle is represented by the scale at the right. Flooding condition sampling events are designated by F in each Figure.

Table 67. Comparisons of the fish assemblages collected seasonally with bag seines during spring (Sp), summer (Su) and fall (Fa) on Garcitas and Carancahua Creeks. Percent contribution (%) to the average dissimilarity; and the ratio ($\delta avg_{(i)}$ / SD $_{(\delta i)}$) are listed for each species. A dashed line (-) represents no species contribution to the comparison.

	Sp vs. Su		Sp vs. Fa		Su vs. Fa	
Species	**%**	**Ratio**	**%**	**Ratio**	**%**	**Ratio**
Gulf menhaden	16.84	1.59	15.30	1.64	10.46	0.82
Bay anchovy	8.55	1.31	11.81	1.36	10.56	1.31
Grass shrimp	6.72	1.10	6.63	1.25	5.7	1.02
Brown shrimp	6.19	0.96	5.28	0.85	2.31	0.49
Spot	5.41	1.17	5.02	1.13	1.59	0.44
Western mosquitofish	4.82	1.08	4.32	1.16	5.65	1.16
Atlantic croaker	4.78	1.17	4.56	1.15	-	-
Striped mullet	4.52	1.08	2.67	0.69	4.06	1.06
White shrimp	4.37	0.68	9.79	1.19	11.01	1.27
Sailfin molly	3.00	0.81	3.48	0.72	5.13	0.97
Blue crab	2.93	1.22	3.36	1.13	3.97	1.15
Tidewater silverside	2.77	0.87	2.07	0.91	2.94	0.89
Pinfish	2.56	1.06	2.04	0.91	1.72	0.66
Blue catfish	2.32	0.84	2.70	0.81	3.53	0.98
Bay whiff	2.18	0.67	1.83	0.56	1.18	0.62
Family Unionidae	1.85	0.57	-	-	1.75	0.50
Gulf killifish	1.62	0.52	-	-	1.57	0.45
Family Macrobrachium	1.58	0.62	1.91	0.77	1.17	0.52
Mojarra species	1.55	0.47	0.89	0.61	2.24	0.67
Ladyfish	1.36	0.72	0.84	0.56	0.87	0.49
Lepomis species	1.33	0.50	-	-	1.56	0.55
Sand seatrout	1.25	0.54	-	-	1.59	0.61
Hogchoker	1.22	0.71	1.57	0.66	2.23	0.86
Southern flounder	1.16	0.93	0.87	0.69	0.93	0.79
Saltmarsh topminnow	-	-	1.20	0.58	1.21	0.53
Naked goby	-	-	1.18	0.73	1.27	0.7
Bluegill	-	-	1.17	0.64	1.42	0.64
			-			
Total Percent Dissimilarity	72.8		76.22		68.00	

catch). MDS configurations of the trawl collections are shown in Fig. 53. No differences among the stations were detected in the trawl collections within either Garcitas Creek (Global R = 0.038, *prob*. = 0.273) or Carancahua Creek (Global R = -0.047; *prob*. = 0.735; see means plot MDS of Fig. 54). The flooding event samples formed more of a cohesive group with the trawls than was the case with the bag seines, with most of these samples falling out in the upper portions of the MDS space. Some of the flooding event samples resulted in zero catches, so to include these samples into the analysis, a dummy variable was added to all samples (catch = 1). The addition of this dummy variable (+d) is noted in the upper legend of each Figure. All the stations within each study stream were then pooled together, and tested for differences between the control and impacted stream with an ANOSIM. While the stations appear to form internally cohesive groups within the means plot MDS space of Fig. 54 (stations within a common stream fall out closer to each other, as well as a consistent grouping of upper, middle, and lower stations along the y-axis), no differences in the trawl-based communities were identified between the two streams.

SIMPER analysis for the Impacted vs. Control ANOSIM is presented in Table 68. While many marine fishes were far more abundant on Carancahua Creek (e.g., bay anchovy, gulf menhaden, Atlantic croaker, and spotted seatrout), the relative proportion of each to the overall community composition within each stream was similar (total percent dissimilarity = 61.68). Seasonality was also seen in the trawl catches from Garcitas Creek, as shown in Fig. 55a (Global R = 0.282, *prob*. = 0.001; spring and fall were significantly different from each other, with summer collections ranging across the other seasons, see Table 69). The catch of gulf menhaden is indicative of this seasonality (see Fig. 55b), with high catch rates of this species throughout all stations during the spring and summer seasons. The effect of flood events on trawl catches is also evident in the Fig. 55b, as many flood events from the spring of 2003 had very low abundance of gulf menhaden during the season that this species is most abundant.

Gill Nets

Gill nets on Garcitas Creek were equally ineffective in terms of the total number of individuals collected. Only 1,051 fishes representing 28 species were recorded. Additionally, a total of 4 blue crabs comprised the invertebrate collection taken from Garcitas Creek. Like Tres Palacios, the gill nets recorded a very different nekton community when compared to the bag seines or trawls. Gill net catches were dominated by blue catfish (35 %), spotted gar (8.9 %), hardhead catfish (8.6 %), and gizzard shad (8.5 %). Smallmouth buffalo, red drum, and gulf menhaden all comprised only a small fraction of the gill net catches (each around 6 %). Bay anchovies, because of their small size, were essentially absent from the gill nets.

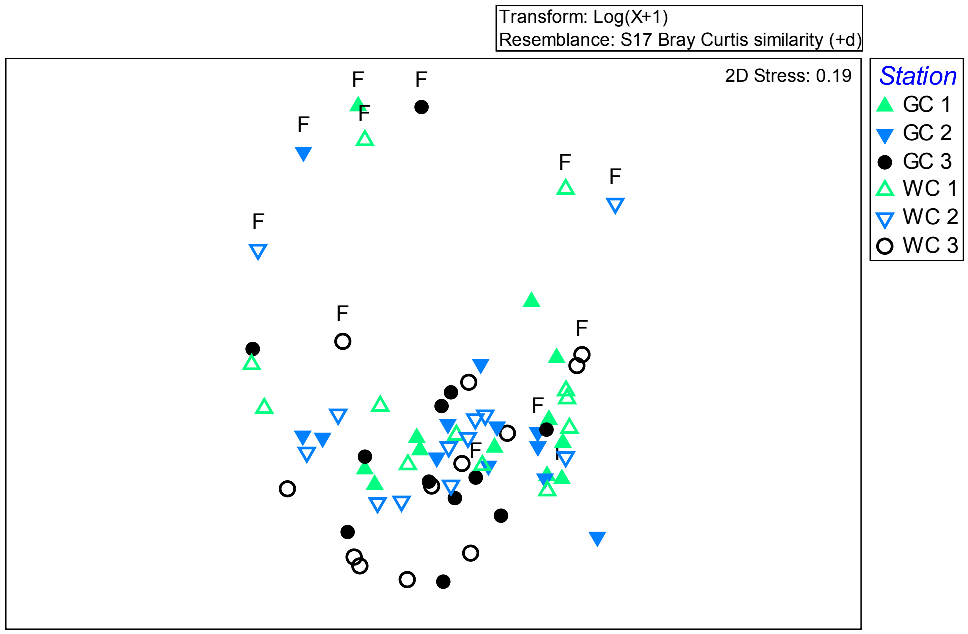


Figure 53. MDS configuration of the stations based on trawl collections from Garcitas and Carancahua Creeks. Flood samples identified (F).

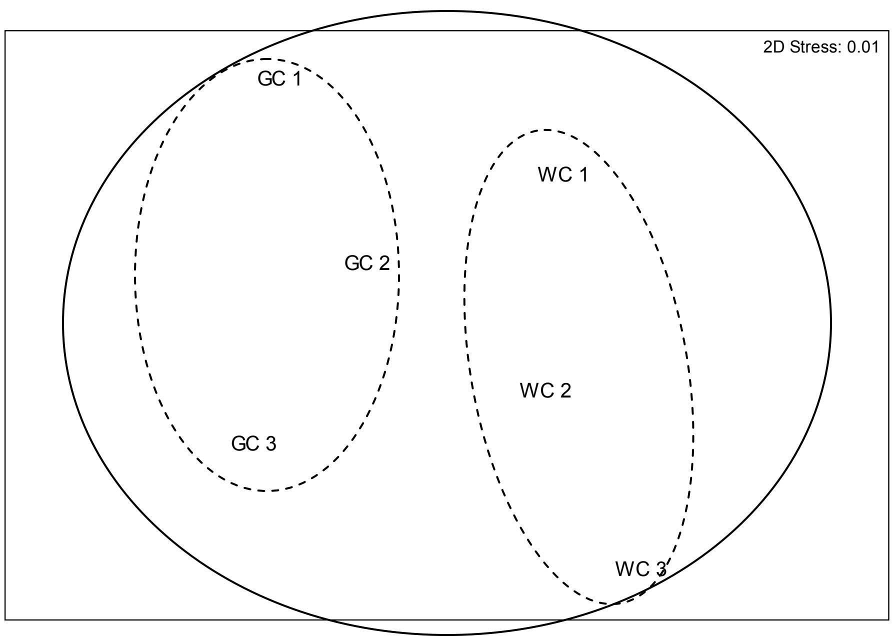
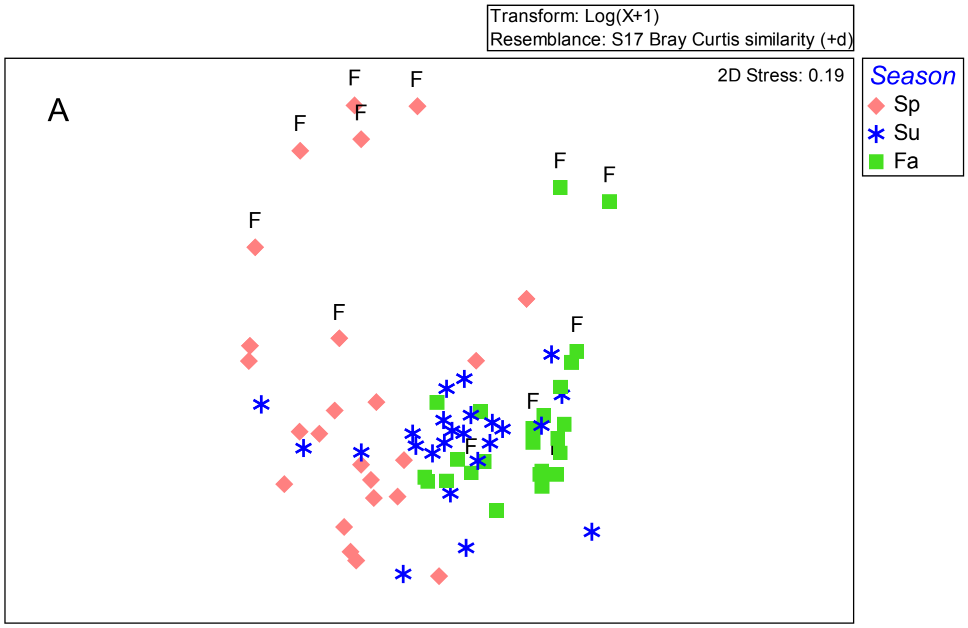


Figure 54. Means plot MDS ordination of the stations based on trawl collections from Garcitas and Carancahua Creeks. Stations within an ellipse (dashed lines represent within stream comparisons; solid lines across stream comparisons) are not significantly different (ANOSIM $p > 0.05$).

Table 68. The contributions of selected individual species to the total average dissimilarity between fish assemblages as measured by trawls in the Impacted (Garcitas Creek = Group I) and Control (Carancahua Creek = Group C) streams. Average abundance (Av. Abund), as measured by number per hour; percent contribution (%) to the average dissimilarity; and the ratio ($\delta avg_{(i)}$ / SD $_{(\delta i)}$) are listed for each species. Species are listed order of relative contribution to the total dissimilarity.

Species	Group I Av. Abund	Group C Av. Abund	%	Ratio
Bay anchovy	1665.46	2123.05	20.09	0.93
Gulf menhaden	1289.64	2221.44	19.83	1.11
Blue catfish	3.11	31.88	10.57	1.06
Atlantic croaker	60.28	167.47	8.66	0.79
White shrimp	2.90	32.56	5.94	0.82
Blue crab	3.78	2.44	4.24	0.66
Sand seatrout	0.56	16.60	4.22	0.63
Spot	2.22	6.11	3.28	0.56
Family Macrobrachium	0.11	1.33	2.45	0.44
Grass shrimp	1.33	1.14	2.22	0.48
Brown shrimp	3.61	3.06	1.85	0.44
Gizzard shad	0.44	0.22	1.30	0.41
Spotted gar	0.22	0.94	1.30	0.41
Hogchoker	0.11	0.42	1.29	0.39
Silver perch	0.22	4.11	0.99	0.32
Red drum	0.78	0.33	0.92	0.28
Total Percent Dissimilarity			61.68	



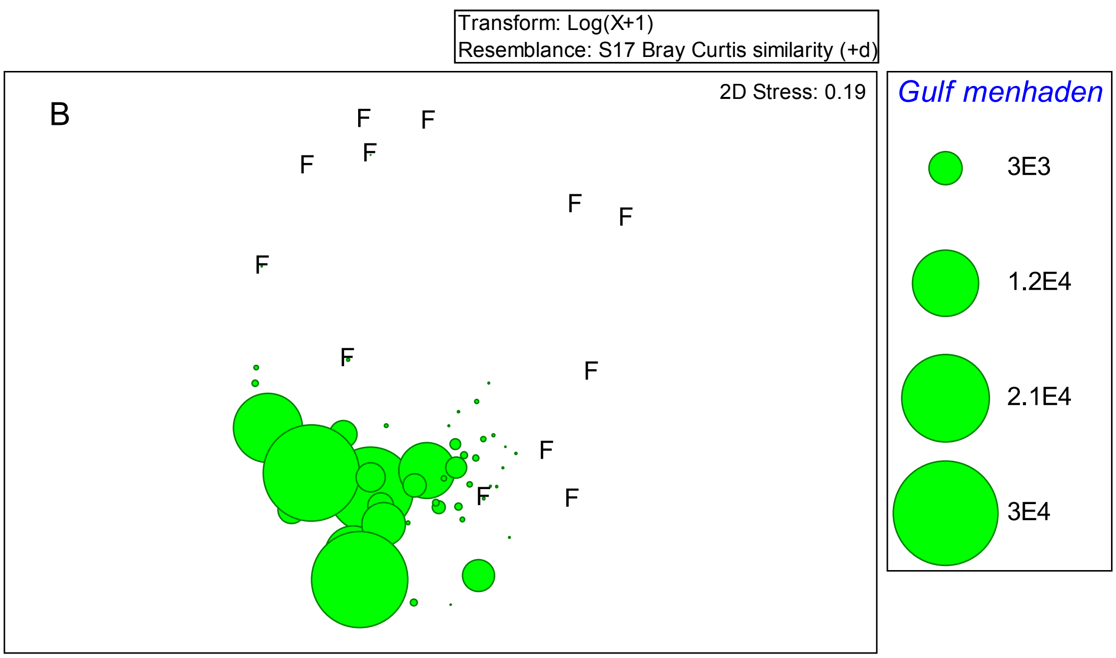


Figure 55. MDS configuration of the stations based on trawl collections from Garcitas and Carancahua Creeks. Station configuration based on Fig. 53, but overlaid onto each station are: A = season of collection, and B = gulf menhaden CPUE. Size of each circle is represented by the scale at the right. Flooding condition sampling events are designated by F in each Figure.

Table 69. Comparisons of the fish assemblages collected seasonally with trawls during spring (Sp), summer (Su) and fall (Fa) on Garcitas and Carancahua Creeks. Percent contribution (%) to the average dissimilarity; and the ratio ($\delta avg_{(i)}$ / SD $_{(\delta i)}$) are listed for each species. A dashed line (-) represents no species contribution to the comparison.

	Sp vs. Su		Sp vs. Fa		Su vs. Fa	
Species	**%**	**Ratio**	**%**	**Ratio**	**%**	**Ratio**
Bay anchovy	22.31	1.05	25.41	1.01	15.93	0.93
Gulf menhaden	18.67	1.10	17.97	1.32	23.81	1.20
Atlantic croaker	12.11	1.28	11.83	1.30	1.74	0.36
Blue catfish	9.58	1.11	8.25	0.83	12.16	1.27
White shrimp	4.53	0.67	5.13	0.82	8.68	1.02
Spot	4.47	0.72	3.70	0.70	1.52	0.32
Sand seatrout	4.39	0.63	1.90	0.47	6.80	0.82
Blue crab	4.36	0.59	2.92	0.63	6.03	0.73
Brown shrimp	2.53	0.57	2.06	0.53	-	-
Grass shrimp	1.78	0.48	2.56	0.57	1.75	0.40
Family Macrobrachium	1.17	0.39	2.52	0.50	2.52	0.47
Silver perch	1.15	0.34	-	-	1.79	0.40
Ladyfish	1.09	0.40	-	-	-	-
Spotted gar	1.08	0.42	1.10	0.41	1.54	0.42
Hogchoker	-	-	1.49	0.51	1.45	0.44
Gizzard shad	-	-	1.25	0.39	1.92	0.47
Red drum	-	-	1.22	0.34	1.60	0.35
Naked goby	-	-	-	-	1.13	0.37
Total Percent Dissimilarity	66.36		74.36		51.32	

MDS configurations of the gill net collections are shown in Fig. 56. Although no differences in the nekton communities were evident within either tidal stream (Tres Palacios Global R = 0.112; *prob*. = 0.115; Carancahua Creek Global R = 0.160; *prob*. = 0.064), there was a significant difference in the overall nekton communities between the impacted (Gracitas Creek) and the control (Carancahua Creek) streams after pooling all the within-stream samples (Global R = 0.199, *prob*. = 0.001; see means plot MDS of Fig. 57). SIMPER results for this ANOSIM comparison is presented in Table 70. Blue catfish, spotted gar, and gizzard shad, three species that were prominent in both tidal systems, were identified as the species most responsible for this difference. Blue catfish were consistently found in higher abundance in Garcitas Creek, while spotted gar and gizzard shad were found in higher abundance in Carancahua Creek (each species contributed a large proportion to the total dissimilarity and had ratio vales > 1.10). These differences in abundance for blue catfish and spotted gar are shown in Fig. 58, with the stations on the Impacted stream enclosed within the dotted line ellipse, and the stations from the Control stream enclosed in the solid line ellipse. While the overall communities between the two streams was identified as significantly different (R = 0.199), this low of an R value is reflective of the large amount of variability in the gill net collections. This variability in the gill net communities is confirmed in the lack of any significant seasonality in the nekton as recorded by this gear (Global R = 0.050; *prob*. = 0.274).

Benthic Macroinvertebrate / Infaunal Collections – Tres Palacios and Carancahua Creek

Benthic infaunal sampling was conducted once per season, in conjunction with the sediment analysis collections. Similar to the sediment analysis, the infauna from the stream-middle and the stream-side were analyzed separately. MDS configurations of the middle collections are shown in Fig. 59. No sampling of the benthic infauna took place during any flooding conditions. As can be seen in the scattering of the stations within Fig. 59, the infauna community was highly variable at each station within each stream. Similar numbers of taxa were collected from both the impacted and reference streams (25 total taxa from each stream; a complete taxonomic list of benthic infauna is presented in Appendix 8). Within Tres Palacios, the upper, middle, and lower stations all had very similar infaunal communities (Global R = -0.103, *prob*. = 0.712), dominated by polychaetes (*Streblospio benedicti*), oligochaetes, and chironomids. Within Carancahua Creek, the upper and middle stations shared many of the same dominant organisms as found in Tres Palacios, but the lower station was distinct in that numerous Hydrobiidae (gastropods from the phylum Mollusca) were encountered (Global R = 0.343, *prob*. = 0.014). Hydrobiidae were also collected from upper and middle stations on Tres Palacios, leading to the overlapping communities among the stations as seen in means plot of Fig. 60. The presence of seasonality was not evident from either stream (Tres Palacios Global R = 0.166, *prob*. = 0.226; Carancahua Creek Global R = 0.148; *prob*. = 0.244).

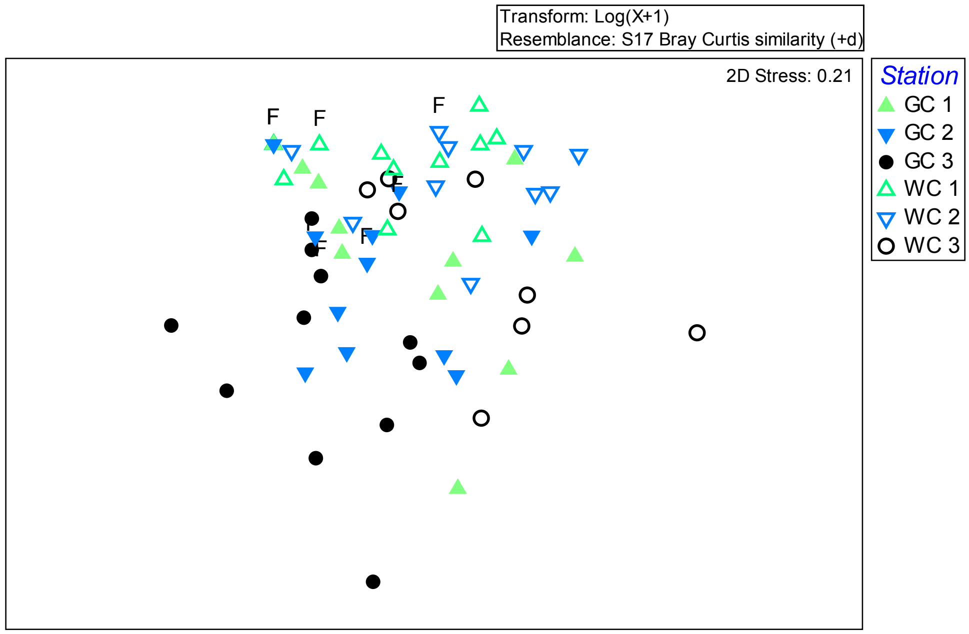


Figure 56. MDS configuration of the stations based on gill net collections from Garcitas and Carancahua Creeks. Flood samples identified (F).

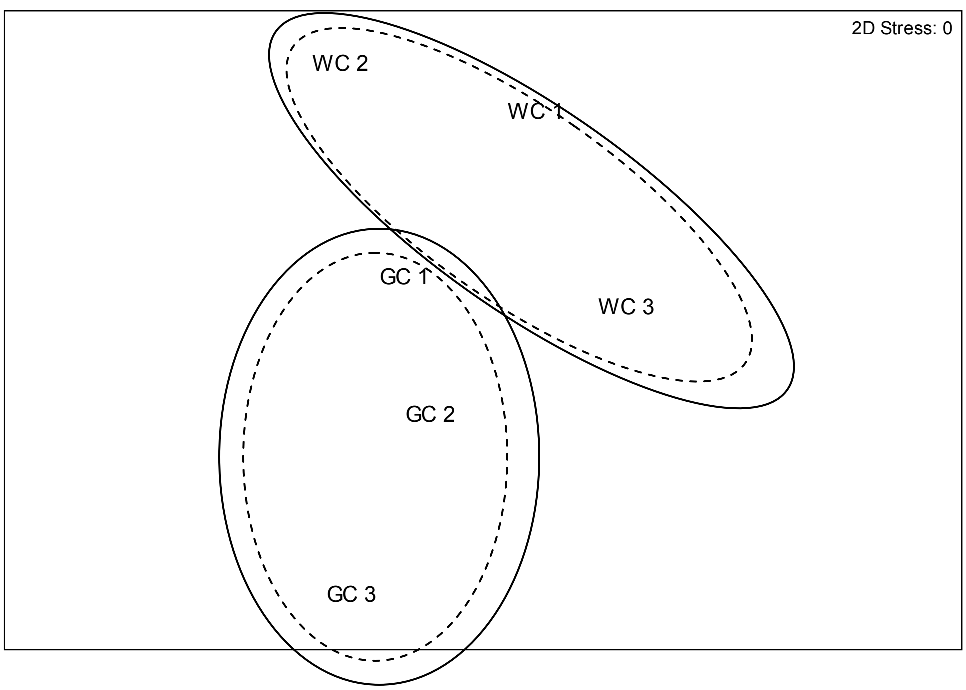


Figure 57. Means plot MDS ordination of the stations based on gill net collections from Garcitas and Carancahua Creeks. Stations within an ellipse (dashed lines represent within stream comparisons; solid lines across stream comparisons) are not significantly different (ANOSIM *p* > 0.05).

Table 70. The contributions of selected individual species to the total average dissimilarity between fish assemblages as measured by gill nets in the Impacted (Garcitas Creek = Group I) and Control (Carancahua Creek = Group C) streams. Average abundance (Av. Abund), as measured by number per hour; percent contribution (%) to the average dissimilarity; and the ratio ($\delta avg_{(i)}$ / SD $_{(\delta i)}$) are listed for each species. Species are listed order of relative contribution to the total dissimilarity. A dashed line (-) represents no species contribution to the comparison.

Species	Group C Av.Abund	Group I Av.Abund	%	Ratio
Blue catfish	0.187	0.758	20.35	1.19
Spotted gar	0.433	0.181	15.02	1.12
Gizzard shad	0.337	0.148	12.03	1.18
Smallmouth buffalo	0.215	0.120	9.14	0.94
Red drum	0.187	0.102	8.18	0.98
Hardhead catfish	0.235	0.200	7.06	0.58
Gulf menhaden	0.043	0.124	4.21	0.50
Gafftopsail catfish	0.008	0.086	3.07	0.70
Longnose gar	0.027	0.039	2.51	0.67
Scaled sardine	0.003	0.070	2.42	0.48
Striped mullet	0.061	0.013	2.27	0.42
Silver perch	-	0.050	1.73	0.29
White crappie	0.005	0.022	1.36	0.41
Black drum	0.016	0.024	1.30	0.54
Total Percent Dissimilarity			72.28	

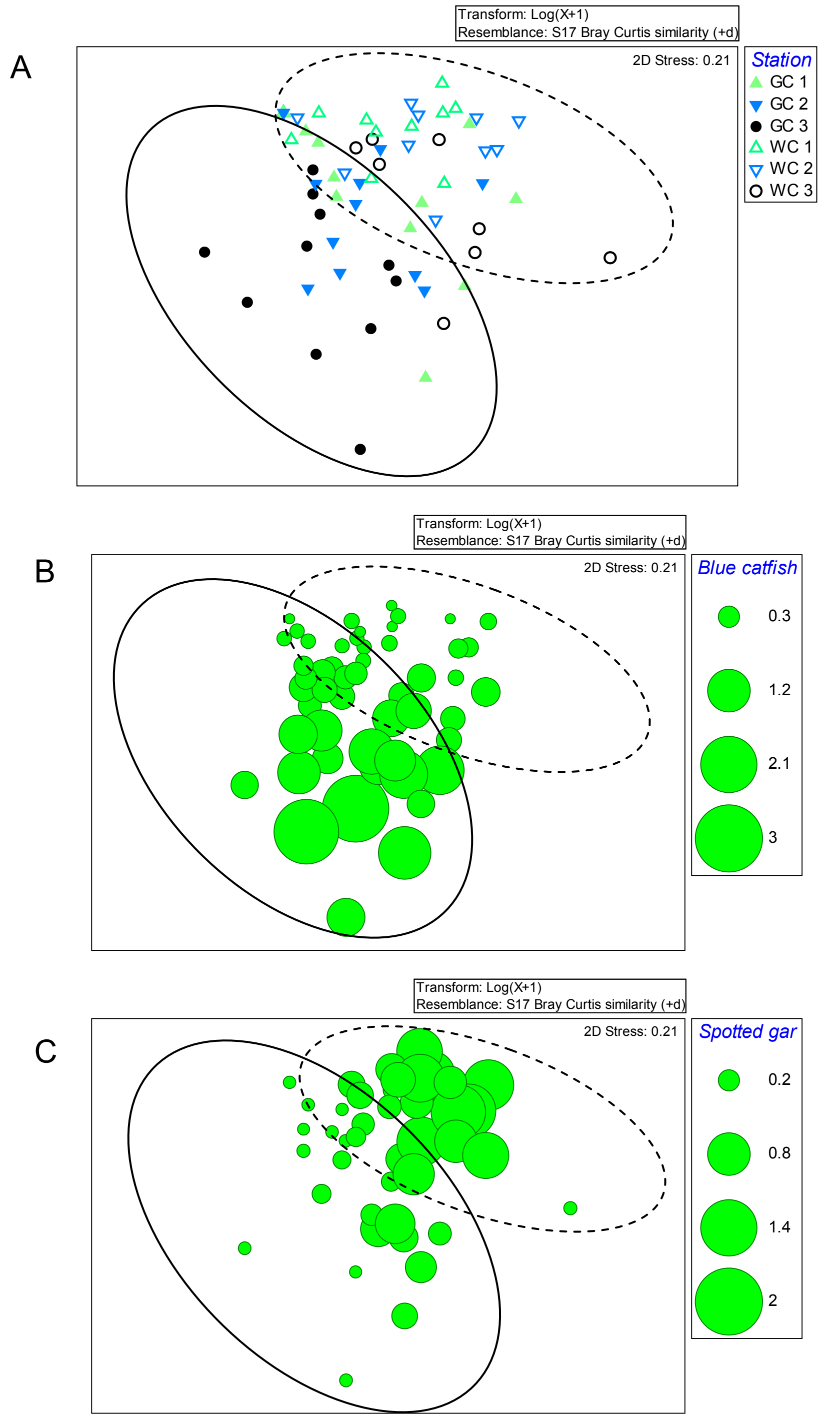


Figure 58. MDS configuration of the stations based on gill net collections from Garcitas and Carancahua Creeks. A =Station configuration identical to Fig. 56; B = blue catfish CPUE overlay; and C = spotted gar CPUE overlay. Size of each circle is represented by the scale at the right. Control stream enclosed in dashed ellipse, impacted within solid ellipse.

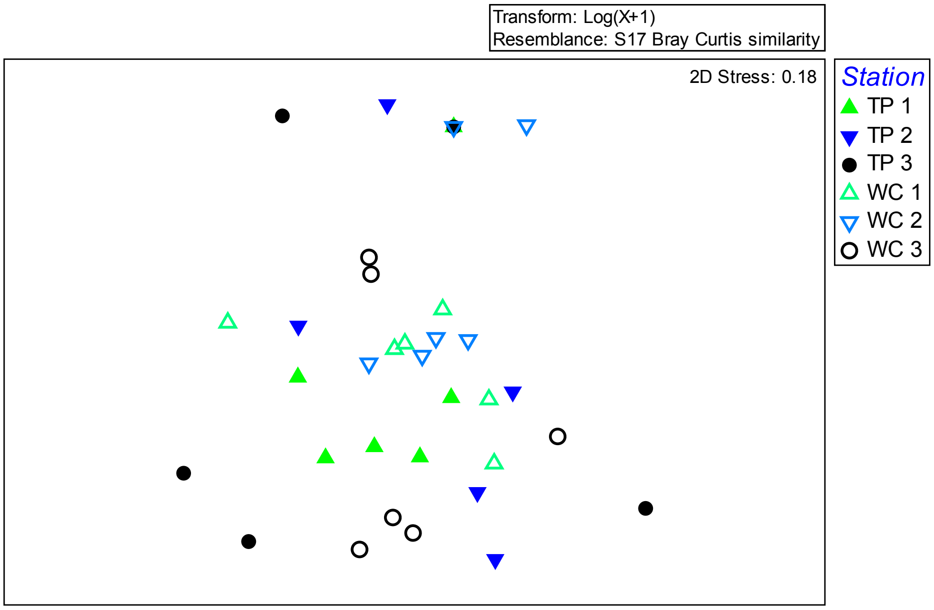


Figure 59. MDS configuration of the stations based on benthic infauna (middle) collections from Tres Palacios and Carancahua Creeks.

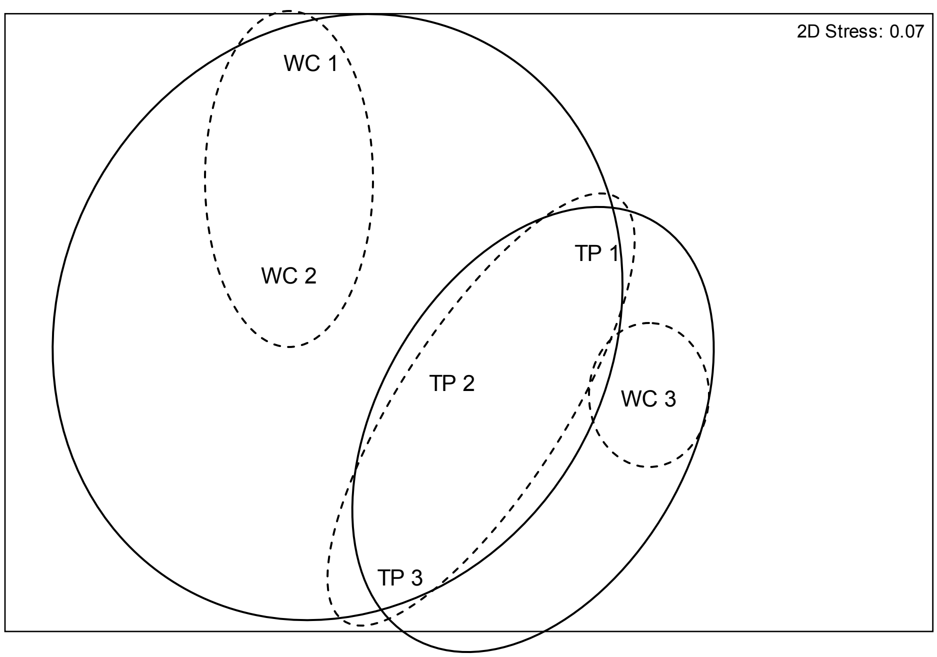


Figure 60. Means plot MDS ordination of the stations based on benthic infauna (middle) collections from Tres Palacios and Carancahua Creeks. Stations within an ellipse (dashed lines represent within stream comparisons; solid lines across stream comparisons) are not significantly different (ANOSIM $p > 0.05$).

The side infaunal collection MDS is shown in Fig. 61. While the side collections were much more diverse than the middle collections in terms of numbers of taxa collected (51 from Tres Palacios and 31 from Carancahua Creek), no significant differences in the overall communities were found within each stream (upper, middle, and lower stations all had similar infaunal communities [Tres Palacios Global R = 0.084, *prob*. = 0.241; Carancahua Creek Global R = -0.056, *prob*. = 0.725]). The side-sediment infaunas were dominated by amphipods (*Corophium louisianum*), and polychaetes (*Polydora ligni*), as well as the oligochaetes, and chironomids that were characteristic of the middle collections. No siginificant differences were found between the two streams (Fig. 62). Like the middle collections, seasonality was not detected in the benthic infauna collected from either stream (Tres Palacios Global R = 0.009, *prob*. = 0.489; Carancahua Creek Global R = 0.083; *prob*. = 0.277).

Benthic Macroinvertebrate / Infaunal Collections – Garcitas and Carancahua Creek

MDS configuration of the middle collections are shown in Fig. 63. More taxa were collected from the reference stream (25 total taxa from Carancahua Creek as opposed to 20 taxa from Garcitas Creek). No overall difference in the benthic communities were detected within the stations on Garcitas Creek (Global R = -0.241, *prob*. = 0.929; see means plot of Fig. 64. The middle sediments on Garcitas Creek were similarly dominated primarily by polychaetes (*Streblospio benedicti*), oligochaetes, and chironomids. Although Hydrobiidae were not collected as frequently within Garcitas Creek, they were restricted in their distribution to the lower-most station. The presence of seasonality was not detected in the middle sediments collections within Garcitas Creek (Global R = 0.185, *prob*. = 0.192).

The MDS configuration of the Garcitas Creek side collections are shown in Fig. 65. The numbers of taxa collected from the stream-side were more equitable when compared to the reference stream (30 from Garcitas Creek and 31 from Carancahua Creek). Like the middle collections, no significant differences in the overall communities were found within the stations on Garcitas Creek (Global R = 0.157, *prob*. = 0.226; see means plot of Fig. 66). The side-sediment communities were dominated by polychaetes (*Laeonereis culveri*), oligochaetes, and chironomids. While amphipods (*Corophium louisianum*) were collected from the middle and lower station on Garcitas Creek, they were far less abundant when compared to the side-sediment collections from the reference stream. Seasonality was not detected in the benthic infauna side collections from Garcitas Creek (Global R = 0.167; *prob*. = 0.116).

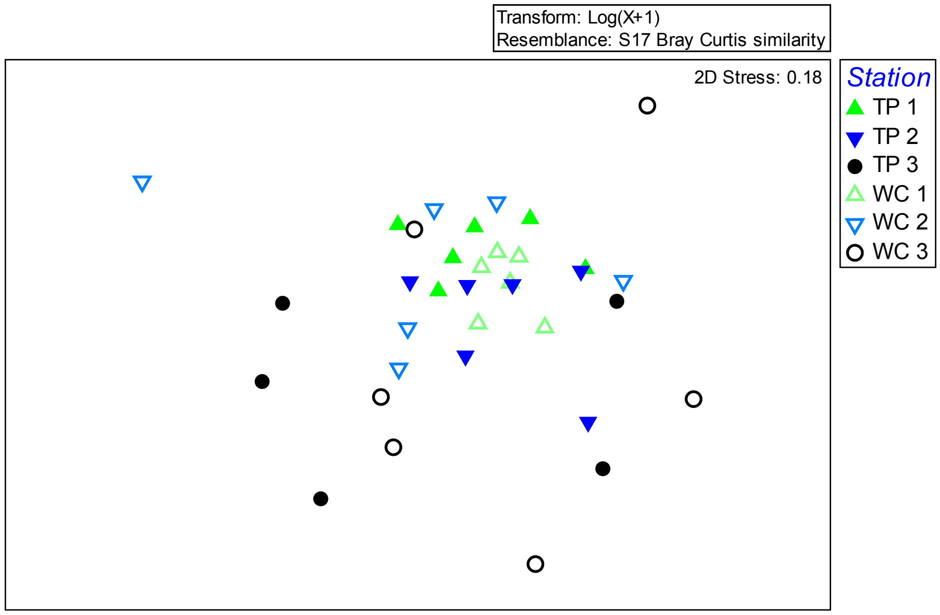


Figure 61. MDS configuration of the stations based on benthic infauna (side) collections from Tres Palacios and Carancahua Creeks.

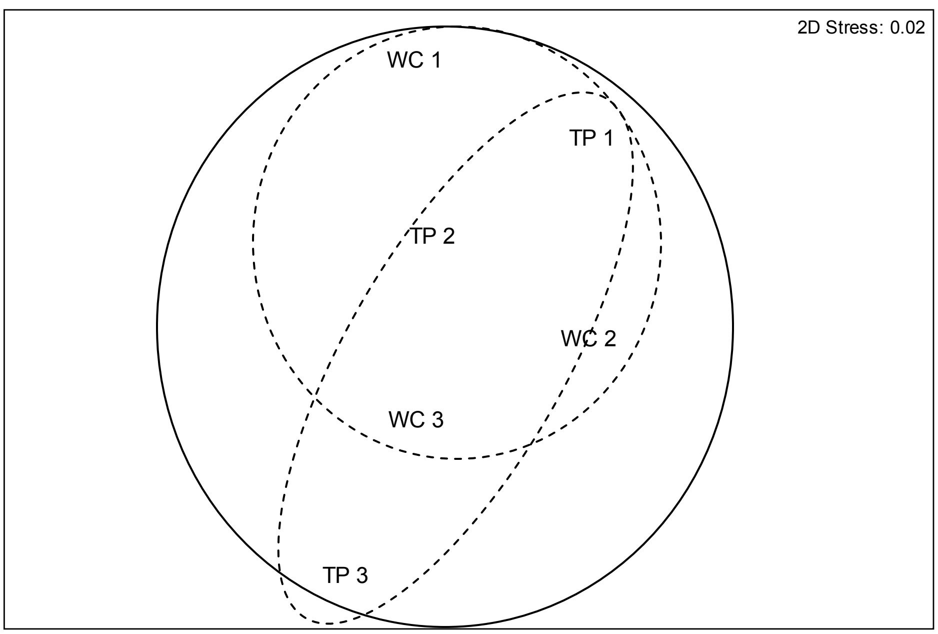


Figure 62. Means plot MDS ordination of the stations based on benthic infauna (side) collections from Tres Palacios and Carancahua Creeks. Stations within an ellipse (dashed lines represent within stream comparisons; solid lines across stream comparisons) are not significantly different (ANOSIM $p > 0.05$).

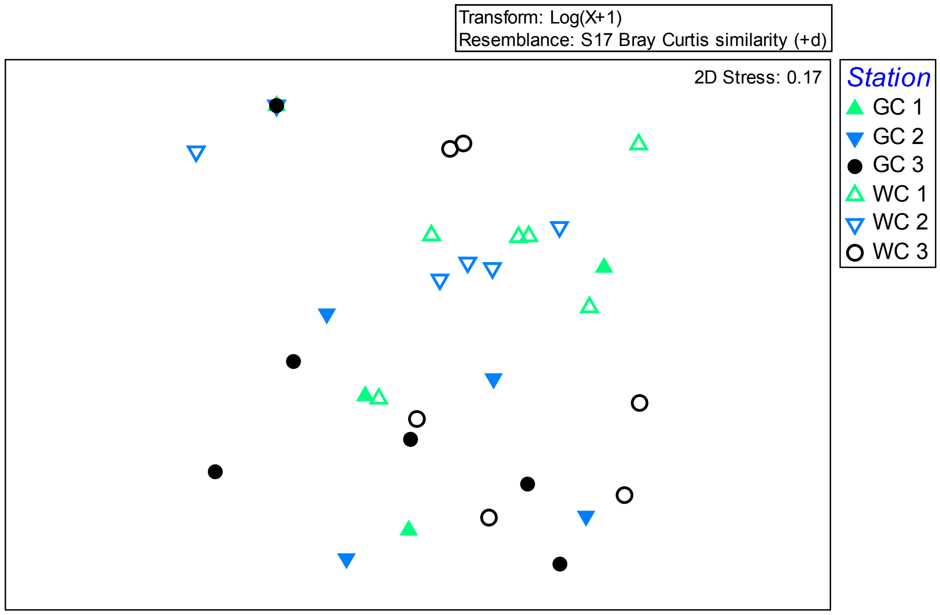


Figure 63. MDS configuration of the stations based on benthic infauna (middle) collections from Garcitas and Carancahua Creeks.

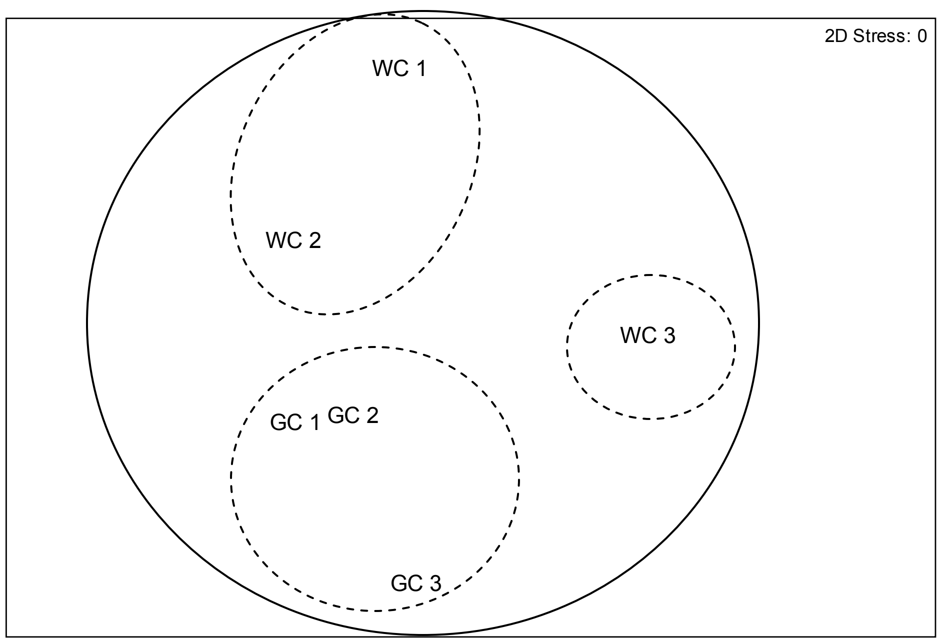


Figure 64. Means plot MDS ordination of the stations based on benthic infauna (middle) collections from Garcitas and Carancahua Creeks. Stations within an ellipse (dashed lines represent within stream comparisons; solid lines across stream comparisons) are not significantly different (ANOSIM *p* > 0.05).

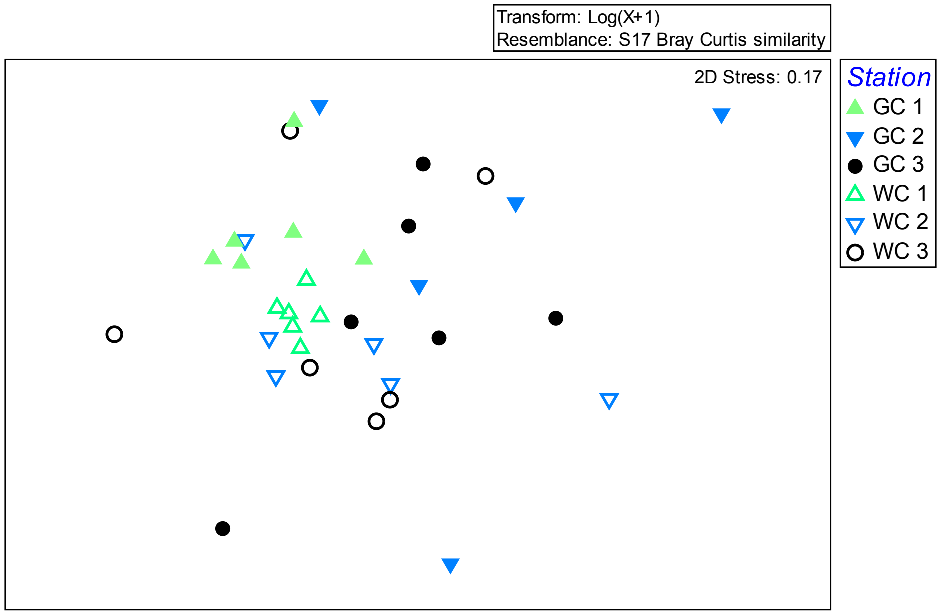


Figure 65. MDS configuration of the stations based on benthic infauna (side) collections from Garcitas and Carancahua Creeks.

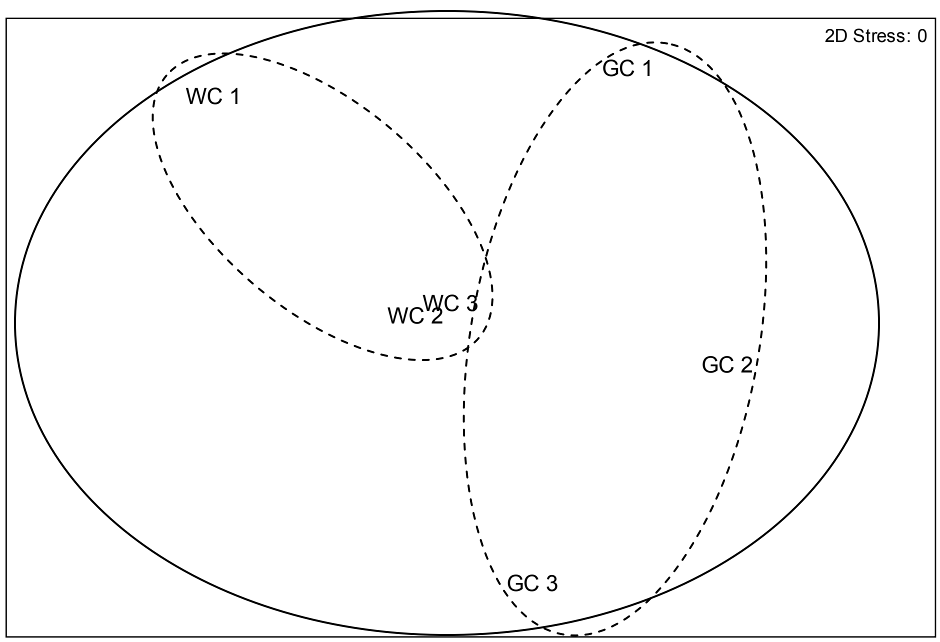


Figure 66. Means plot MDS ordination of the stations based on benthic infauna (side) collections from Garcitas and Carancahua Creeks. Stations within an ellipse (dashed lines represent within stream comparisons; solid lines across stream comparisons) are not significantly different (ANOSIM $p > 0.05$).

Aquatic Invertebrate Collections – Tres Palacios and Carancahua Creek

Unlike the benthic invertebrate sampling that was collected only once per season, aquatic invertebrate sampling was conducted at the scale of the nekton collections, or twice per season. For the first year of sampling, taxonomic identification of the individuals collected with the D-frame nets were taken to the lowest possible classification (for many phyla, the lowest possible classification was to the species level). Due to the high level of diversity in the aquatic invertebrate collections, taxonomic classifications during the second year of the study were taken only to the family level. For all analysis, family level classifications are used to compare the study stream to the reference stream.

A total of 11,023 individuals from 88 families were collected with D-frame nets from Tres Palacios. Carancahua Creek had as many families collected (88 unique families), but many more individuals (27,742 total aquatic invertebrates). This is a very similar pattern to that seen with the nektonic bag seine collections, with far fewer individuals being collected from Tres Palacios. A complete taxonomic list of families and the total number of individuals collected from each tidal stream is presented in Appendix 9. MDS configuration of the D-frame net collections is presented in Fig. 67. Flooding condition samples were less evident with the D-frame nets than with many of the gears used to sample the nekton. On both streams, the upper and middle stations had similar aquatic invertebrate communities, and the lower stations were significantly different from upper and middle stations (Tres Palacios Global R = 0.449; *prob*. = 0.001; Carancahua Creek Global R = 0.201; *prob*. = 0.012; see means MDS plot of Fig. 68).

The upper and middle stations on each stream were pooled together and compared to the lower stations in order to uncover which families were responsible for any differences in communities between the stations (SIMPER analysis presented in Table 71). Insects tended to be far more abundant at the Upper group of stations (e.g., Corixidae, Chironomidae, Homoptera, Zygoptera, Lepidoptra, and Ephemeroptera), while marine crustaceans (Gammaridae, Corophiidae, and Portunidae) and molluscs (Hydrobiidae) were more characteristic of the Lower group of stations. Examples of these differences are shown in Fig. 69, with the Corixidae much more abundant in the Upper group, and the Corophiidae more abundant in the Lower group. Other forms of these three groups (insects, crustaceans, and mollusks) ranged throughout each streams, and were found in equal abundance in the upper, middle, and lower stations (Gerreidae, Baetidae, Taltridae, and Physidae; see Table 71). While Mysidacea are a marine crustacean, they were, on average, an order of magnitude more abundant in the Upper group of stations.

Seasonality was identified in the D-frame net collections within both Tres Palacios (Global R = 0.325; *prob*. = 0.001) and Carancahua Creek (Global R -= 0.170; *prob*. = 0.013). Within both streams, the spring and summer as well as

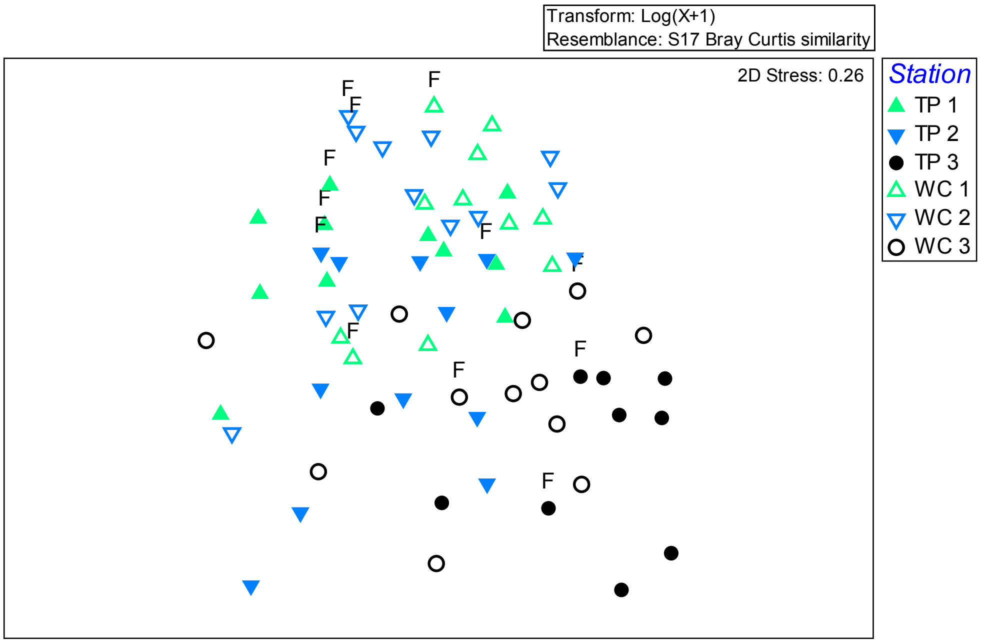


Figure 67. MDS configuration of the stations based on D-frame net collections from Tres Palacios and Carancahua Creeks. Flood samples identified (F).

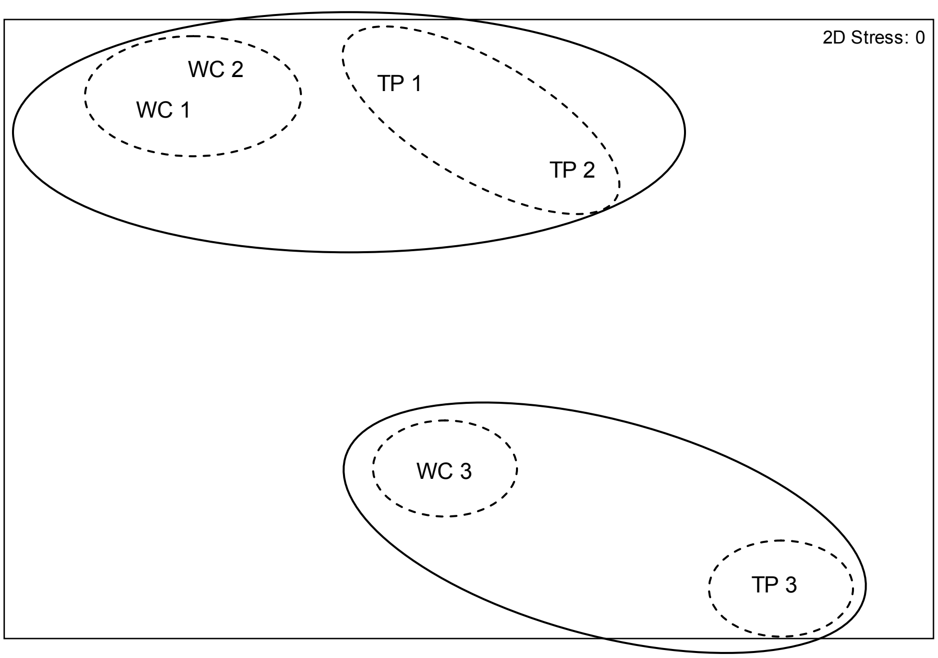


Figure 68. Means plot MDS ordination of the stations based on D-frame net collections from Tres Palacios and Carancahua Creeks. Stations within an ellipse (dashed lines represent within stream comparisons; solid lines across stream comparisons) are not significantly different (ANOSIM *p* > 0.05).

Table 71. The contributions of selected individual species to the total average dissimilarity between aquatic invertebrate assemblages as measured by D-frame nets in the upper and middle (Group U) and lower (Group L) stations on Tres Palacios and Carancahua Creek. Average abundance (Av. Abund), as measured by number per 5 minute sample; percent contribution (%) to the average dissimilarity; and the ratio ($\delta avg_{(i)}$ / SD $_{(\delta i)}$) are listed for each species. Species are listed order of relative contribution to the total dissimilarity. A dashed line (-) represents no species contribution to the comparison.

Species	Group U Av.Abund	Group L Av.Abund	%	Ratio
Mysidacea	432.80	42.68	7.49	1.27
Gammaridae	0.11	97.41	6.38	0.94
Corixidae	51.59	10.23	5.72	1.34
Hydrobiidae	16.46	39.59	4.96	1.14
Gerridae	15.59	17.91	4.92	0.99
Corophiidae	0.26	20.77	4.84	1.02
Oligochaeta	14.72	0.95	4.59	1.23
Chironomidae	96.54	34.55	4.28	1.53
Portunidae	0.80	13.64	4.10	1.15
Araneae	9.96	6.32	2.87	1.23
Baetidae	4.65	2.55	2.47	0.71
Ampharetidae	9.02	0.55	2.45	0.82
Homoptera	3.76	1.82	2.41	0.79
Zygoptera	3.43	0.45	2.05	0.85
Hydrophilidae	2.46	0.23	2.00	0.85
Physidae	3.43	3.50	1.94	0.55
Spionidae	1.39	1.41	1.91	0.70
Lepidoptera	2.76	0.18	1.87	0.75
Taltridae	1.96	1.14	1.79	0.73
Ceratopogonidae	1.54	0.23	1.54	0.86
Dysticidae	0.78	0.23	1.28	0.81
Caenidae	0.83	0.27	1.18	0.76
Ephemeroptera	1.39	0.09	1.15	0.60
Taltroidea	1.96	1.14	1.13	0.52
Haliplidae	1.07	-	1.06	0.61
Hyalellidae	0.89	0.59	1.04	0.52
Coenagrionidae	1.35	0.05	1.03	0.55
Sphaeromatidae	0.30	0.73	1.03	0.61
Mactridae	0.70	0.18	1.03	0.65
Planorbidae	0.89	0.09	0.86	0.59
Curculionidae	0.52	0.14	0.76	0.55
Total Percent Dissimilarity			67.95	

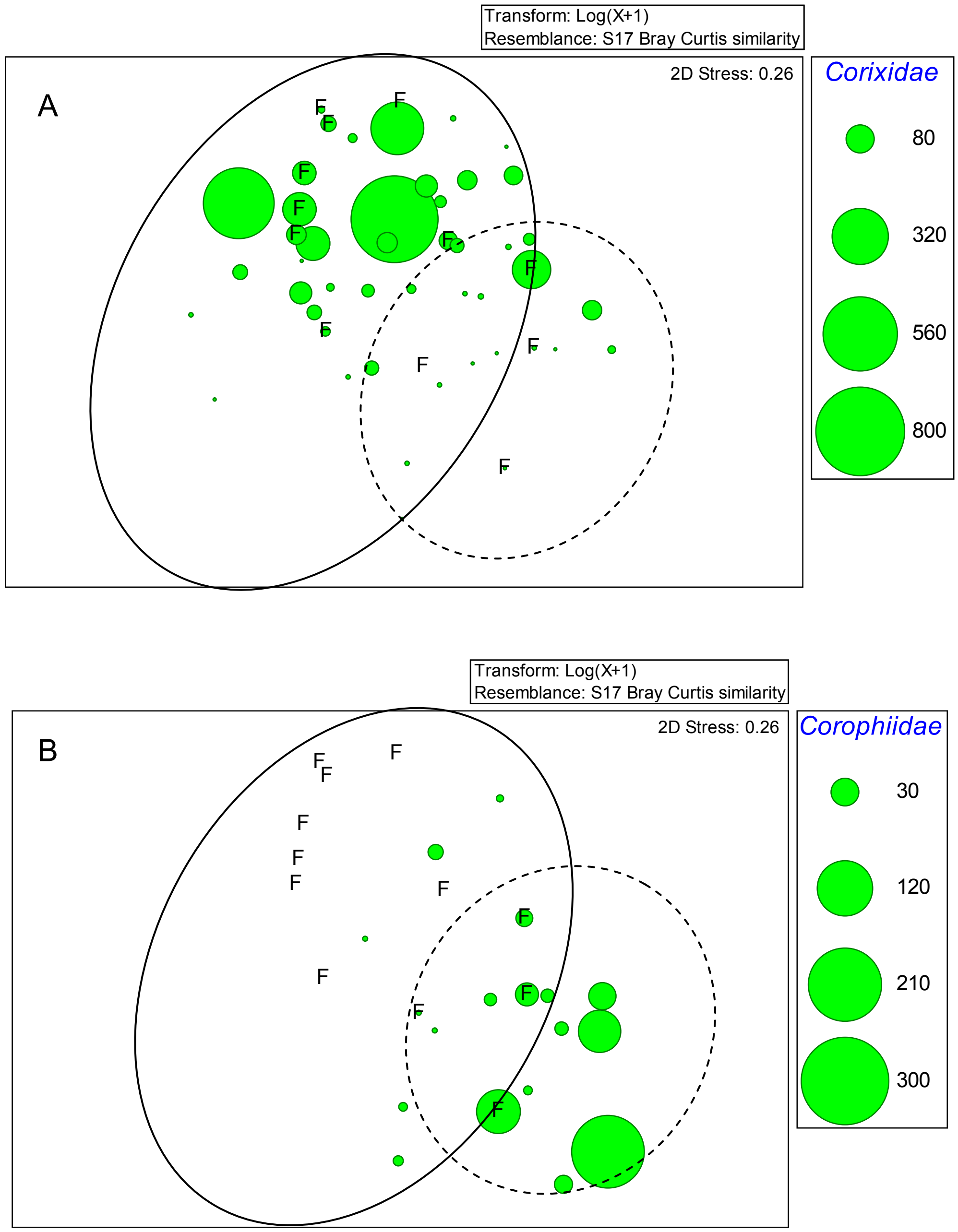


Figure 69. MDS configuration of the stations based on D-frame net collections from Tres Palacios and Carancahua Creeks. Station configuration identical to Fig. 67; A = Corixidae CPUE overlay; and B = Corophiidae CPUE overlay. Size of each circle is represented by the scale at the right. Upper stations enclosed in solid ellipse, Lower stations within the solid ellipse. Flood samples (F) identified for reference.

spring and fall collections had significantly different aquatic invertebrate communities. Summer and fall communities overlapped, and these two seasons were not significantly different.

Aquatic Invertebrate Collections – Garcitas and Carancahua Creeks

D-frame net collections on Garcitas Creek resulted in the capture 18,889 individuals from 85 different families. From the MDS configuration of this gear (Fig. 70), the aquatic invertebrate community mirrored that of the nekton community as measured by the bag seines, namely there was much overlap between the upper and middle stations, and overlap between the middle and lower stations (Global R = 0.206; *prob*. = 0.011). The upper and lower stations were significantly different from each other (pairwise comparison R = 0.533; *prob*. = 0.002; see means plot MDS presented in Fig. 71).

The middle station on Garcitas Creek was pooled with the two lower stations and compared to the Upper group with a SIMPER analysis (Table 72). Many insects families were more common throughout the entire tidal reach on Garcitas Creek (e.g., Corixidae, Chironomidae, Homoptera, Zygoptera, and Orthoptera), while others followed the pattern seen on Tres Palacios (more abundant at the upper stations, e.g., Lepidoptra, Hydrophilidae, and Ephemeroptera, see Table 72). Marine crustaceans (Gammaridae and Portunidae) and molluscs (Hydrobiidae) were again characteristic of the Lower group. Figure 72 shows examples of D-frame net abundance estimates overlaid onto the station configurations for Planorbidae (a freshwater mollusk found at the Upper stations group) and Gammaridae (a marine amphipod crustacean characteristic of the Lower station group). The general overlap of the communities is evident in Fig. 72a and 72b, with the Lower stations group cutting across the ellipse defining the Upper stations group. Mysidacea were again, on average, an order of magnitude more abundant in the Upper group of stations.

Seasonality was also identified in the D-frame net collections within Garcitas Creek (Global R = 0.125; *prob*. = 0.047), with the spring and summer and the summer and fall communities overlapping. Spring and fall D-frame net collections had significantly different aquatic invertebrate communities.

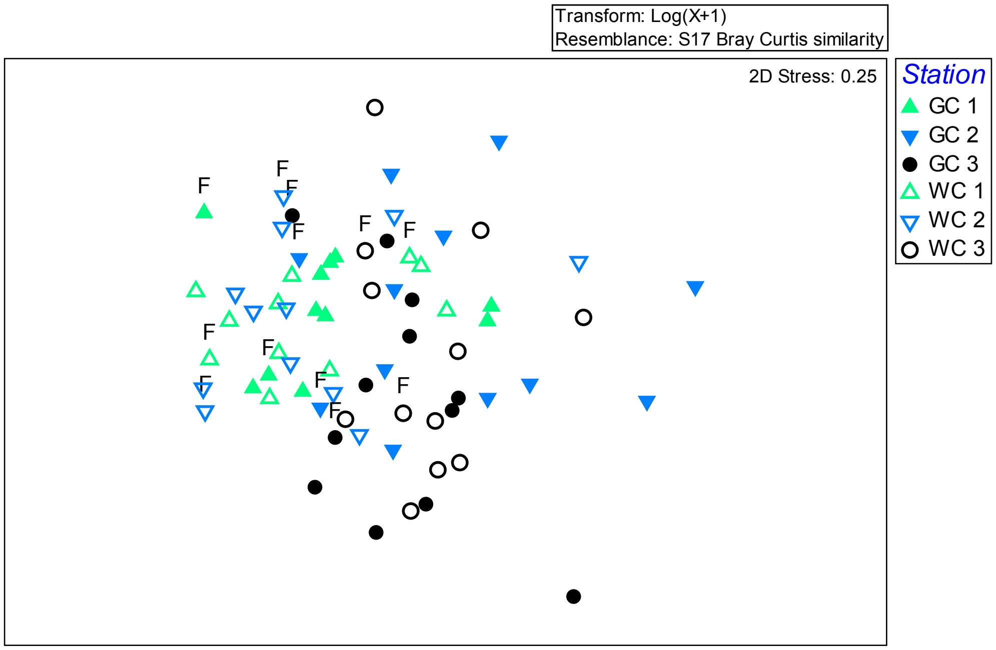


Figure 70. MDS configuration of the stations based on D-frame net collections from Garcitas and Carancahua Creeks. Flood samples identified (F).

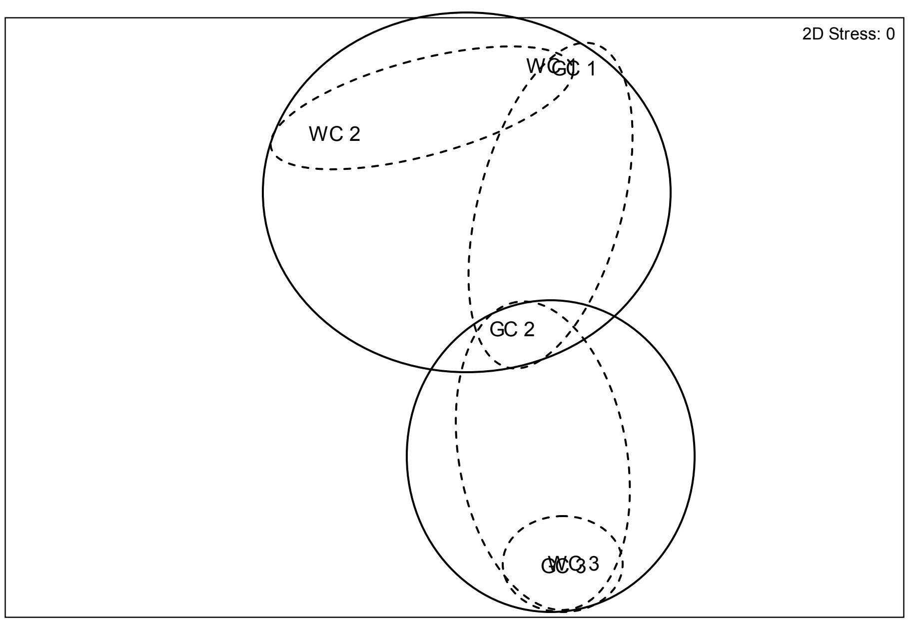
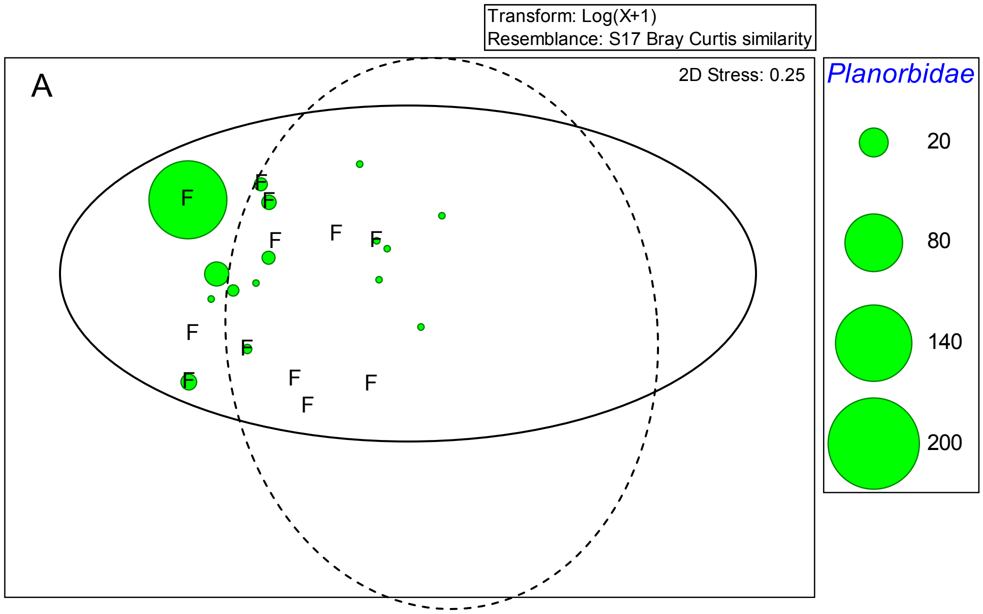


Figure 71. Means plot MDS ordination of the stations based on D-frame net collections from Garcitas and Carancahua Creeks. Stations within an ellipse (dashed lines represent within stream comparisons; solid lines across stream comparisons) are not significantly different (ANOSIM $p > 0.05$).

Table 72. The contributions of selected individual species to the total average dissimilarity between aquatic invertebrate assemblages as measured by D-frame nets in the upper and middle (Group U) and lower (Group L) stations on Garcitas and Carancahua Creeks. Average abundance (Av. Abund), as measured by number per 5 minute sample; percent contribution (%) to the average dissimilarity; and the ratio ($\delta avg_{(i)}$ / SD $_{(\delta i)}$) are listed for each species. Species are listed order of relative contribution to the total dissimilarity.

Species	**Group U Av.Abund**	**Group L Av.Abund**	**%**	**Ratio**
Mysidacea	771.38	60.39	10.05	1.37
Corixidae	52.85	61.86	5.92	1.23
Gerridae	30.18	13.78	4.86	1.11
Hydrobiidae	28.94	27.94	4.80	1.14
Oligochaeta	12.91	0.67	4.50	1.11
Chironomidae	74.56	34.61	4.12	1.29
Homoptera	6.82	8.33	3.31	0.89
Araneae	13.53	11.11	3.10	1.24
Baetidae	5.68	3.22	2.86	0.84
Gammaridae	0.18	18.08	2.72	0.68
Portunidae	0.56	4.92	2.68	0.96
Hydrophilidae	4.82	0.75	2.60	1.05
Taltridae	3.53	3.33	2.41	0.85
Lepidoptera	3.76	0.31	2.28	0.83
Zygoptera	4.03	1.33	2.23	0.86
Corophiidae	1.12	2.39	1.99	0.78
Ampharetidae	2.59	0.25	1.96	0.78
Physidae	4.65	0.22	1.59	0.59
Haliplidae	1.35	0.31	1.55	0.89
Ceratopogonidae	1.50	0.50	1.47	0.85
Ephemeroptera	2.29	0.31	1.46	0.64
Sphaeromatidae	0.24	1.47	1.37	0.67
Hyalellidae	1.18	0.81	1.29	0.64
Coenagrionidae	1.71	0.03	1.28	0.60
Planorbidae	5.38	0.25	1.26	0.69
Dysticidae	0.68	0.33	1.10	0.81
Nepidae	0.97	0.81	1.09	0.69
Caenidae	0.82	0.25	1.00	0.66
Dreissenidae	2.59	0.14	0.98	0.51
Spionidae	0.53	0.44	0.96	0.59
Elmidae	0.88	0.17	0.92	0.46
Orthoptera	0.62	0.44	0.86	0.63
Culicidae	0.82	0.22	0.75	0.48
Taltroidea	1.68	0.25	0.74	0.37
Total Percent Dissimilarity			66.26	



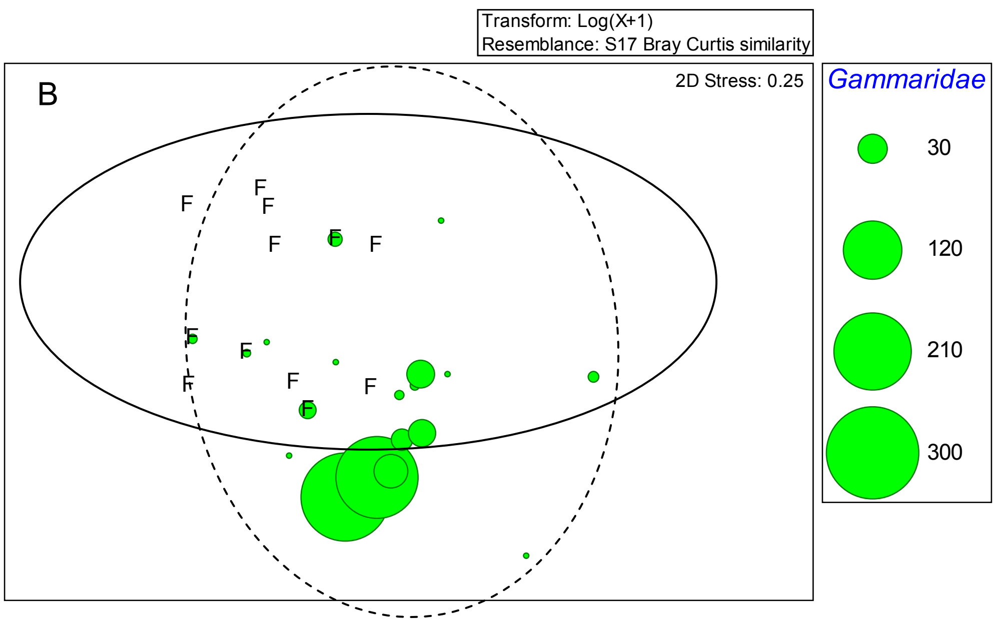


Figure 72. MDS configuration of the stations based on D-frame net collections from Garcitas and Carancahua Creeks. Station configuration identical to Fig. 70; A = Planorbidae CPUE overlay; and B = Gammaridae CPUE overlay. Size of each circle is represented by the scale at the right. Upper stations enclosed in solid ellipse, Lower stations within the solid ellipse. Flood samples (F) identified for reference.

MDS Configuration Agreement – Tres Palacios and Carancahua Creeks

Spearman's rank correlation was used to quantify the degree of agreement among the biological, chemical, and physical MDS configurations, and these correlations are presented in Table 73. The biological sampling was designed to address temporal and spatial changes in community composition across many different trophic levels and life history stages, and as can be seen in Table 73, the only sampling gears that revealed consistent patterns among the stations were the nekton collections of bag seines and trawls. No other biological collections (gill nets, aquatic invertebrates, or benthic infauna) had significant correlations among the MDS configurations. BEST (Biota and/or Environmental Matching) analysis revealed that the agreement between the bag seine and trawl configurations was driven primarily by three species, Atlantic croaker, Family Fundulidae (killifishes and top minnows), and the freshwater goby. As an example, Fig. 73 shows the relationship between bag seine and trawl collections of Atlantic croaker, a species collected in the spring and summer primarily from the lower and middle stations where salinity was generally higher.

Significant agreements between the biotic and abiotic components of ecosystem health were identified between the gill net collections and surface water quality (both field parameter profiles and water chemistry parameters), as well as between the benthic infaunal collections and the sediment composition constituents. Although the gill nets generally captured much older life stages than did either the bag seine or the trawl collections, the communities collected with this gear was the only one to be significantly related to the temporal and spatial changes in surface water quality measurements. Salinity was the only field parameter associated with differences in community composition as measured by gill nets (Fig. 74). BEST analysis revealed that a number of marine species were positively associated with increased salinities (bull shark, gafftopsail catfish, hardhead catfish, sand trout, spotted seatrout) and numerous freshwater taxa were associated with lower salinities (common carp, longnose gar, scaled sardine, spotted gar, and threadfin shad). Completely missing from the significant correlations between the biology and the physical environment MDS configurations were any commonalities of community structure and dissolved oxygen measurements.

The gill net-based community structure differences attributed to water chemistry measurements were also closely linked to salinity-related parameters, namely chloride, sulfate, and total dissolved solids. Salinity-related distributional differences in Atlantic croaker, finescale menhaden, gafftopsail catfish, sheepshead, spot, and spotted seatrout (marine species more abundant in higher salinities) and longnose gar, scaled sardine, spotted gar, and yellow bullhead catfish (freshwater species found in lower salinities) were identified through the BEST analysis procedure. Similar to the surface dissolved oxygen measurement, oxygen-based water chemistry measurements (e.g., BOD, total

Table 73. Matrix of Spearman's rank correlations between MDS configurations of the biological, chemical, and physical components of ecosystem health measures in Tres Palacios and Carancahua Creeks. Only the lower panel of the correlation matrix is presented. Probability of obtaining a larger correlation coefficient by random chance (based on 1,000 permutations) denoted by: * = *prob*. < 0.01, ** = *prob*. < 0.001. Significant correlations ($\rho_s > 0.3$) identified in bold.

	Bag Seine[a]	Trawl[b]	Gill Net[c]	Aquatic Invertebrates[d]	Benthic Infauna[e]	Water Column Profile	Water Quality	Sediments
Bag Seine	___							
Trawl	**0.409****	___						
Gill Net	0.192**	0.247**	___					
Aquatic Invertebrates	0.217**	0.154**	0.154**	___				
Benthic Infauna	0.128	0.233	0.242*	0.185*	___			
Water Column Profile	0.191**	0.178**	**0.467****	0.176*	0.267**	___		
Water Quality	0.266**	0.277**	**0.412****	0.264**	0.260**	**0.543****	___	
Sediments	-0.038	0.048	0.206*	0.130	**0.366***	0.167*	0.130	___

[a]Bag Seines related to surface Water measurements and side Sediments, [b]Trawls related to bottom Water measurements and middle Sediments, [c]Gill Nets related to surface Water measurements and side Sediments, [d]Aquatic Invertebrates related to surface Water measurements and side Sediments, [e]Benthic Infauna related to bottom Water measurements and middle Sediments.

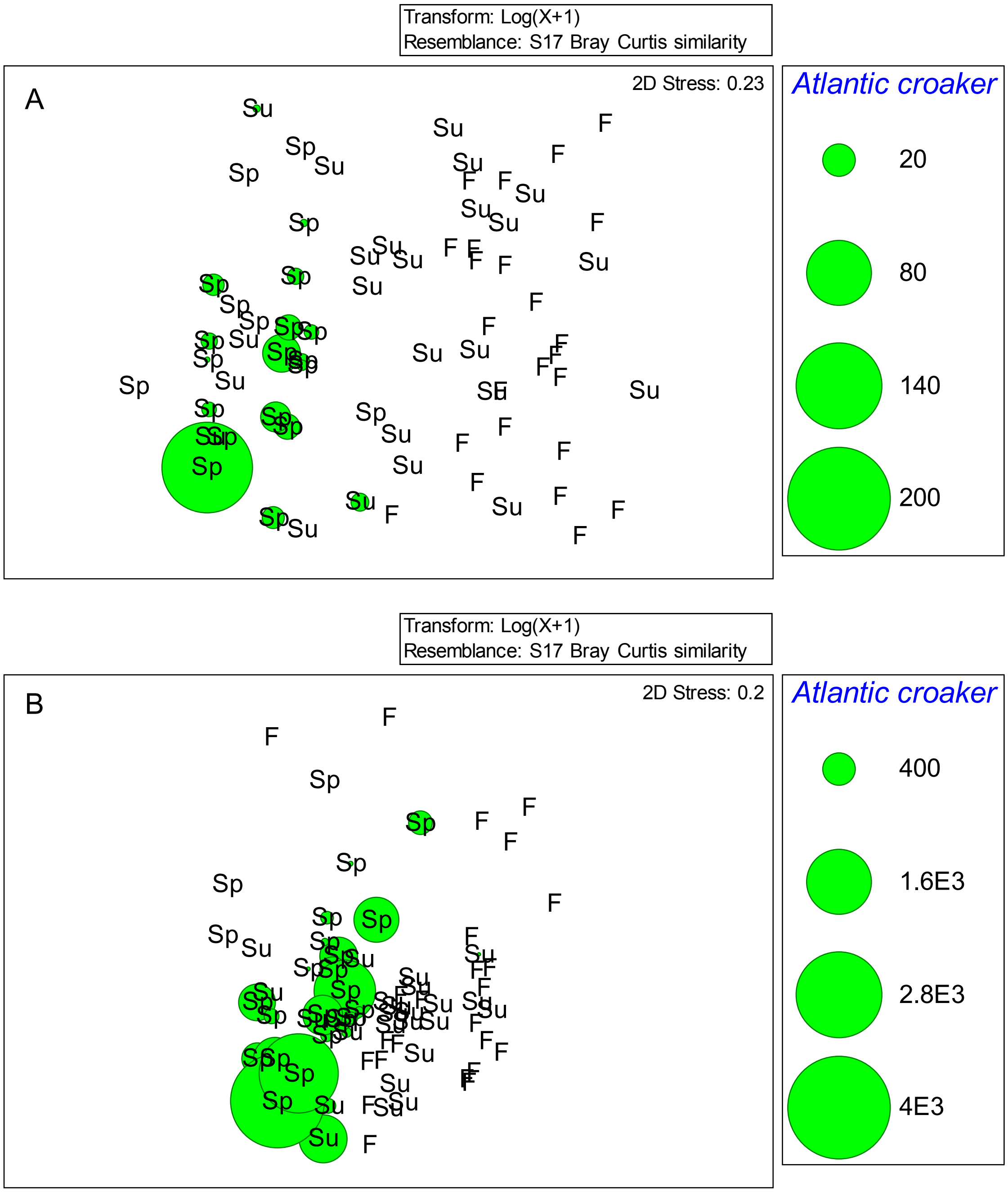


Figure 73. Seasonal MDS configurations of the stations based on A = bag seines and B = trawl collections from Tres Palacios and Carancahua Creeks. Original configurations identical to Fig. 43a for bag seines and Fig. 46a for trawls. Seasonal designations as follows; Sp = Spring, Su = Summer, and F = Fall. Overlaid onto each station is the catch rate for Atlantic croaker as determined by each gear. Size of each circle is represented by the scale at the right.

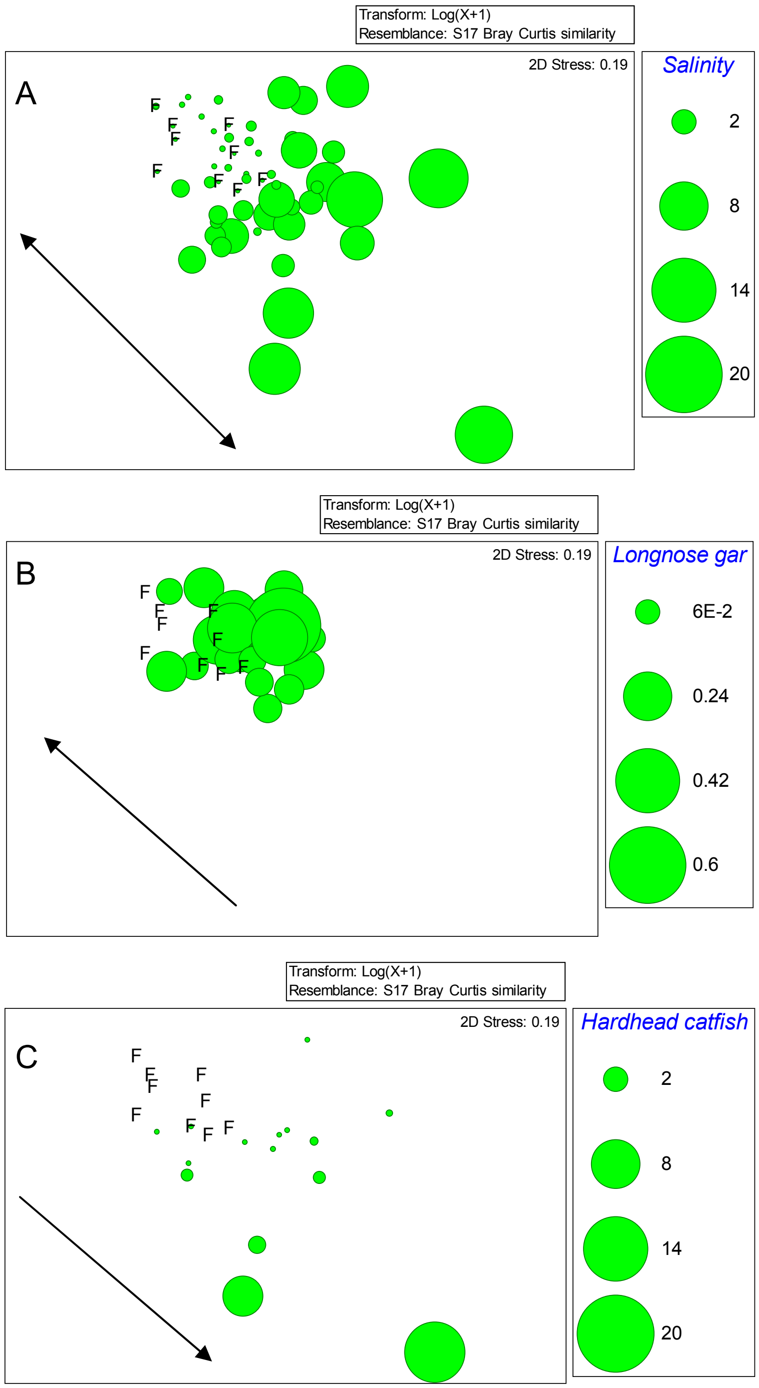


Figure 74. MDS configuration of the stations based on gill net collections from Tres Palacios and Carancahua Creek. A = Configuration identical to Fig. 47, but overlaid with surface water column salinity measurements; B = Catch rates for longnose gar; and C = catch rates for hardhead catfish. Arrows indicate the general direction of the constituent gradient. Size of each circle is represented by the scale at the right.

organic carbon, chlorophyll a, and phaeophytin a) were all unrelated to the gill net-based community structure as identified in the MDS (see Fig. 75).

Benthic infaunal organisms significantly correlated to the sediment composition constituents included *Streblospio benedicti*, *Odostomia laevigata*, *Texadina baretti*, *Parandalia* spp., Hydrobiidae, Mysidacea, and *Exogene dispar* (see Fig. 76). Percent solids was the only sediment composition variable significantly correlated with the biological community configuration. Recalling that percent solids and percent sand were highly related (see PCA analysis of sediment collections, Water and Sediment Samples – Tres Palacios and Carancahua Creek, Table 50 and Fig. 30), the midrange of percent solids and percent sand (30 – 70%) contained the greatest amount on infaunal abundance. Benthic collections containing a large percentage of either clays and silts or gravel tended to have lower abundance levels.

MDS Configuration Agreement – Garcitas and Carancahua Creeks

The degree of agreement of the biological, chemical, and physical MDS configurations between Garcitas and Carancahua Creeks are presented in Table 74. Similar to the patterns of spatial and temporal changes in community structure seen in Tres Palacios and Carancahua Creeks, consistent patterns among the stations within Garcitas and Carancahua Creeks were driven primarily by salinity mediated measures. The highest correlation was found between the abiotic measures of water column profiles and water quality chemistry measurements (ρ_s = 0.618), with chloride, sulfate, fluoride, alkalinity, and nitrite identified as the water quality constituents responsible for the high correlation between the MDS configurations (Fig. 77).

The nekton collections of bag seines and trawls were also correlated (ρ_s = 0.353) and this correlation was driven by many of the same species encountered in nekton collection from Tres Palacios Creek (Atlantic croaker, blue catfish, Family Macrobrachium, gulf menhaden, pink shrimp, silver perch, spotted seatrout, striped mullet, and white shrimp). While the correlation between the trawl and gill net MDS configurations was lower than that found for the bag seine and trawl collections (ρ_s = 0.353, see Table 74), the species identified in the BEST analysis were common to all the gears used for this study (e.g., Atlantic croaker, blue catfish, gafftopsail catfish, gizzard shad, hardhead catfish, smallmouth buffalo, spotted gar, and spotted seatrout).

Within Garcitas Creek and the reference stream, significant agreements between the biotic and abiotic components were only identified between the trawl collections and bottom water quality measurements (Table 74). Again, salinity-mediated constituents were more closely associated with the changes in community composition as measured by this gear (chloride, alkalinity, volatile

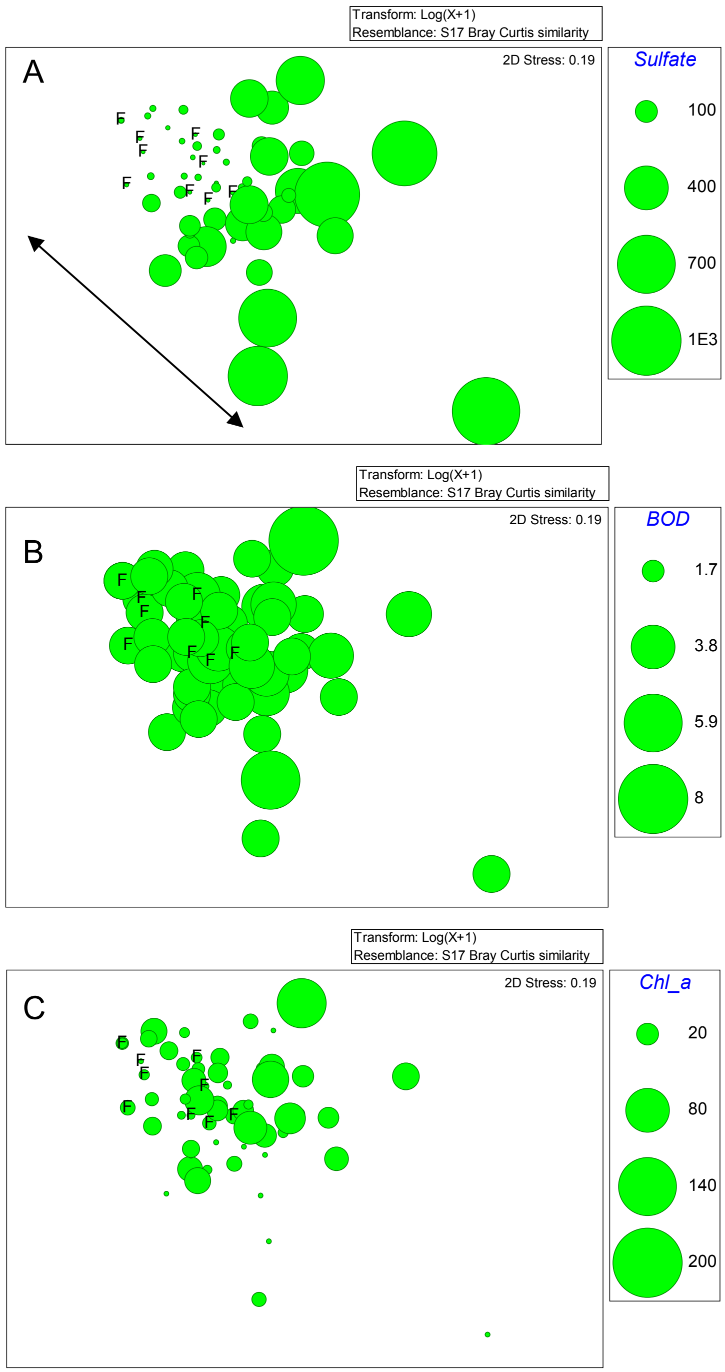


Figure 75. MDS configuration of the stations based on gill net collections from Tres Palacios and Carancahua Creek. A = Configuration identical to Fig. 47, but overlaid with surface water chemistry sulfate measurements; B = Biological Oxygen Demand; and C = Chlorophyll a. Arrows indicate the general direction of the constituent gradient. Figures without an arrow lack constituent gradient. Size of each circle is represented by the scale at the right.

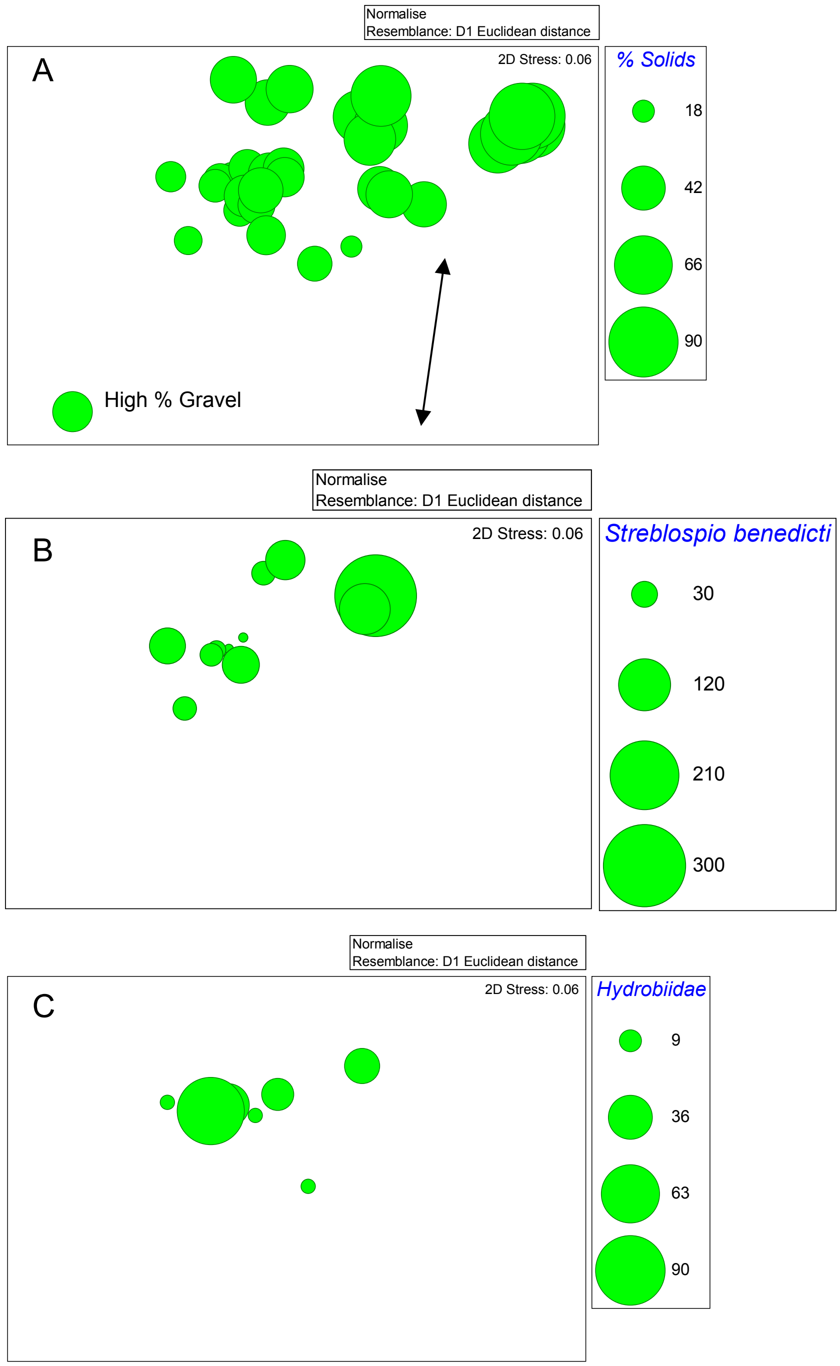


Figure 76. MDS configuration of the stations based on sediment composition parameters (middle collection) from Tres Palacios and Carancahua Creek, overlaid with A = Percent Solids measurement; B = *Streblospio benedicti* catch rates; and C = Hydrobiidae catch rates. Anomalously high % gravel sample identified (compare same sample in Fig. 30). Arrows indicate the general direction of the constituent gradient. Size of each circle is represented by the scale at the right

Table 74. Matrix of Spearman's rank correlations between MDS configurations of the biological, chemical, and physical components of ecosystem health measures in Garcitas and Carancahua Creeks. Only the lower panel of the correlation matrix is presented. Probability of obtaining a larger correlation coefficient by random chance (based on 1,000 permutations) denoted by: * = *prob*. < 0.01, ** = *prob*. < 0.001. Significant correlations ($\rho_s > 0.3$) identified in bold.

	Bag Seine[a]	Trawl[b]	Gill Net[c]	Aquatic Invertebrates[d]	Benthic Infauna[e]	Water Column Profile	Water Quality	Sediments
Bag Seine	___							
Trawl	**0.353****	___						
Gill Net	0.147*	**0.301****	___					
Aquatic Invertebrates	0.194**	0.227*	0.109	___				
Benthic Infauna	0.048	0.141*	0.082	0.091	___			
Water Column Profile	0.166**	0.221**	0.184*	0.250**	0.098	___		
Water Quality	0.212**	**0.381****	0.266**	0.247**	0.052	**0.618****	___	
Sediments	0.002	0.145*	-0.104	0.064	0.152	0.070	0.075	___

[a]Bag Seines related to surface Water measurements and side Sediments, [b]Trawls related to bottom Water measurements and middle Sediments, [c]Gill Nets related to surface Water measurements and side Sediments, [d]Aquatic Invertebrates related to surface Water measurements and side Sediments, [e]Benthic Infauna related to bottom Water measurements and middle Sediments.

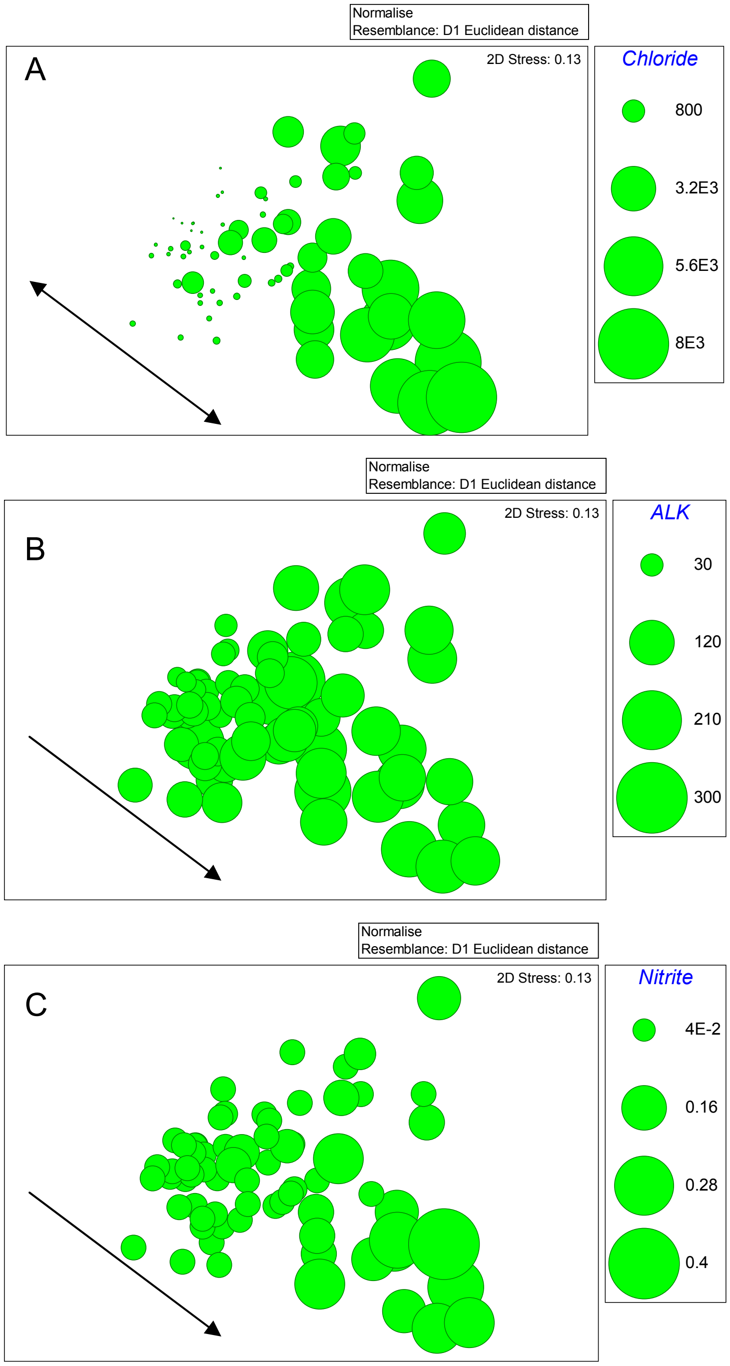


Figure 77. MDS configuration of the stations based on surface water quality collections from Tres Palacios and Carancahua Creek. A = Configuration overlaid with surface water chemistry chloride measurements; B = Alkalinity measurements; and C = Nitrite Nitrogen measurements. Arrows indicate the general direction of the constituent gradient. Size of each circle is represented by the scale at the right.

suspended solids, and phosphorus, see Fig. 78). Salinity-mediated distributional differences in Atlantic croaker, bay anchovy, gafftopsail catfish, gulf menhaden, pink shrimp, silver perch, spot, spotted seatrout, striped mullet, and white shrimp (marine species more abundant in higher salinities) and blue catfish, Macrobranchium, and green gobies (freshwater taxa more abundant in lower salinities) were identified through the BEST analysis procedure.

Average Taxonomic Distinctness – Tres Palacios and Carancahua Creeks

From Fig. 9, the Average Taxonomic Distinctness measure (Δ^*, identified in all subsequent Figures as Delta+) takes the form of Delta+ = 0 if two individuals drawn at random from a sample are the same species; Delta+ = 20, different species from the same genera; Delta+ = 40, different genera from the same family, etc. In order to simplify the biological interpretation of this measure, all invertebrates (from Appendix 7) were excluded from the nekton collections such that the distinctness measures for bag seines, trawls, and gill nets reflects the taxonomic breadth of the fish communities only. Invertebrate collections of the Benthics (both side and middle) and the D-Frame nets include the entire sample lists that appear in Appendices 7 and 8.

Average Delta+ values for the bag seine collections revealed that much of taxonomic diversity was at the Family level (mean Δ^* = 31.98 ± 19.53 SD, see Fig. 79). While the ANOSIM procedure found significant differences in the composition of the nekton communities among the stations (see Nekton Collections – Bag Seines; Fig. 42), a parametric Analysis of Variance of the Delta+ values failed to find any statistical difference among the stations due to a high degree of taxonomic overlap, with many taxa common to each sampling station (Fig. 79a). Seasonality was far more evident ($F_{2,67} = 4.021$, $p = 0.022$), with the spring season having the lowest degree of taxonomic diversity (see Fig. 79b). This result is expected, as these collections were typically dominated by gulf menhaden catches numerically outnumbering other taxa by orders of magnitude at times. The importance of taxonomically-derived seasonality reinforces the seasonal signal found in the MDS configuration presented in Fig. 43a. With bag seines, Delta+ values were not affected by flooding conditions, as the overall diversity of the communities collected during these periods were similar. Compared to the reference stream, Tres Palacios had more total species (48 vs. 41 nekton taxa) as well as a more taxonomically diverse collection of nekton (separate variance $t = -2.014$, df = 67.7, $p = 0.048$, see Fig. 79d).

Trawl collections had markedly lower average Delta+ values (mean Δ^* = 16.02 ± 13.58 SD) than did the bag seine collections, reflecting the lower numbers of taxa that were susceptible to collection with this gear. Of the three sampling stations, the lower stations (TP 3 and WC 3) had the highest nekton diversity, with many different marine Orders (e.g., Scorpaeniformes, Batrachoidiformes, and Tetraodontiformes) collected exclusively from these stations (see Fig. 80a).

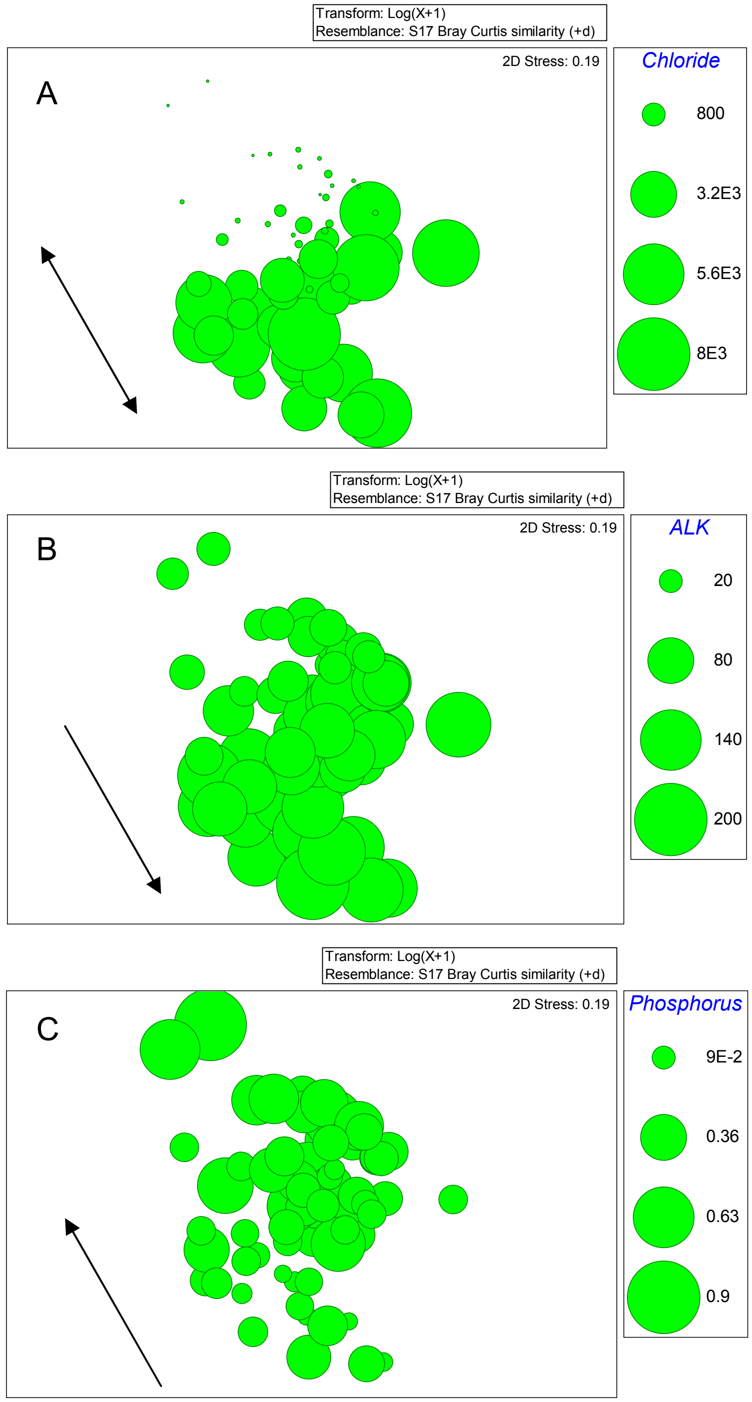


Figure 78. MDS configuration of the stations based on bottom water quality collections from Tres Palacios and Carancahua Creek. A = Configuration overlaid with water chemistry chloride measurements; B = Alkalinity measurements; and C = Phosphorus measurements. Arrows indicate the general direction of the constituent gradient. Size of each circle is represented by the scale at the right.

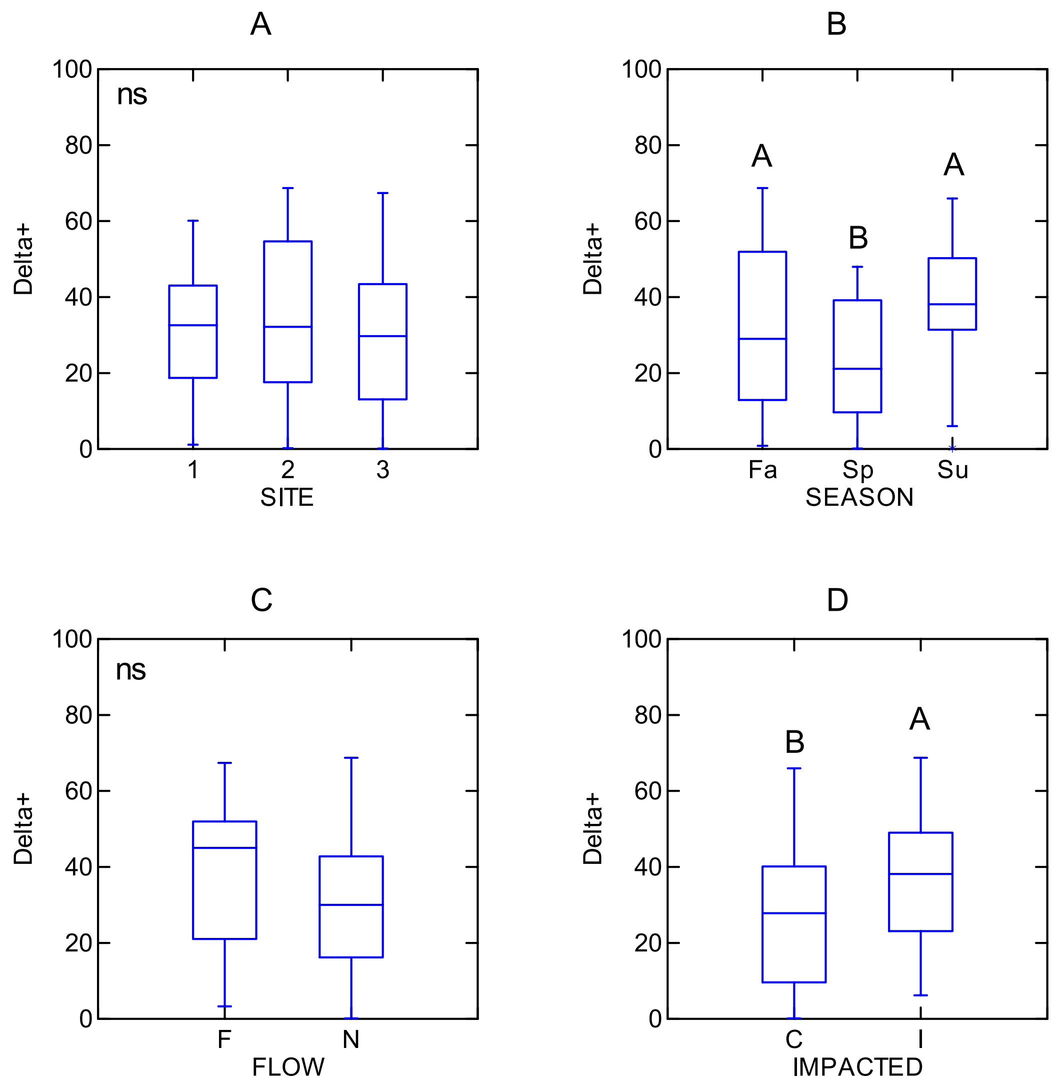


Figure 79. Box plots of Average Taxonomic Diversity values (Delta+) of nekton as recorded by bag seine collections from Tres Palacios and Carancahua Creeks. A = among Site comparisons (1 = upper, 2 = middle, 3 = lower); B = among Season comparisons (Fa = Fall, Sp = Spring, Su = Summer); C = Flow condition comparison (F = Flood, N = Normal); and D = Impacted comparison (C = control – Carancahua Creek, I = Impacted, Tres Palacios Creek). Categories within each plot with the same letter are not significantly different (test results and probability levels for each significant difference reported in the text). No significant difference identified by ns.

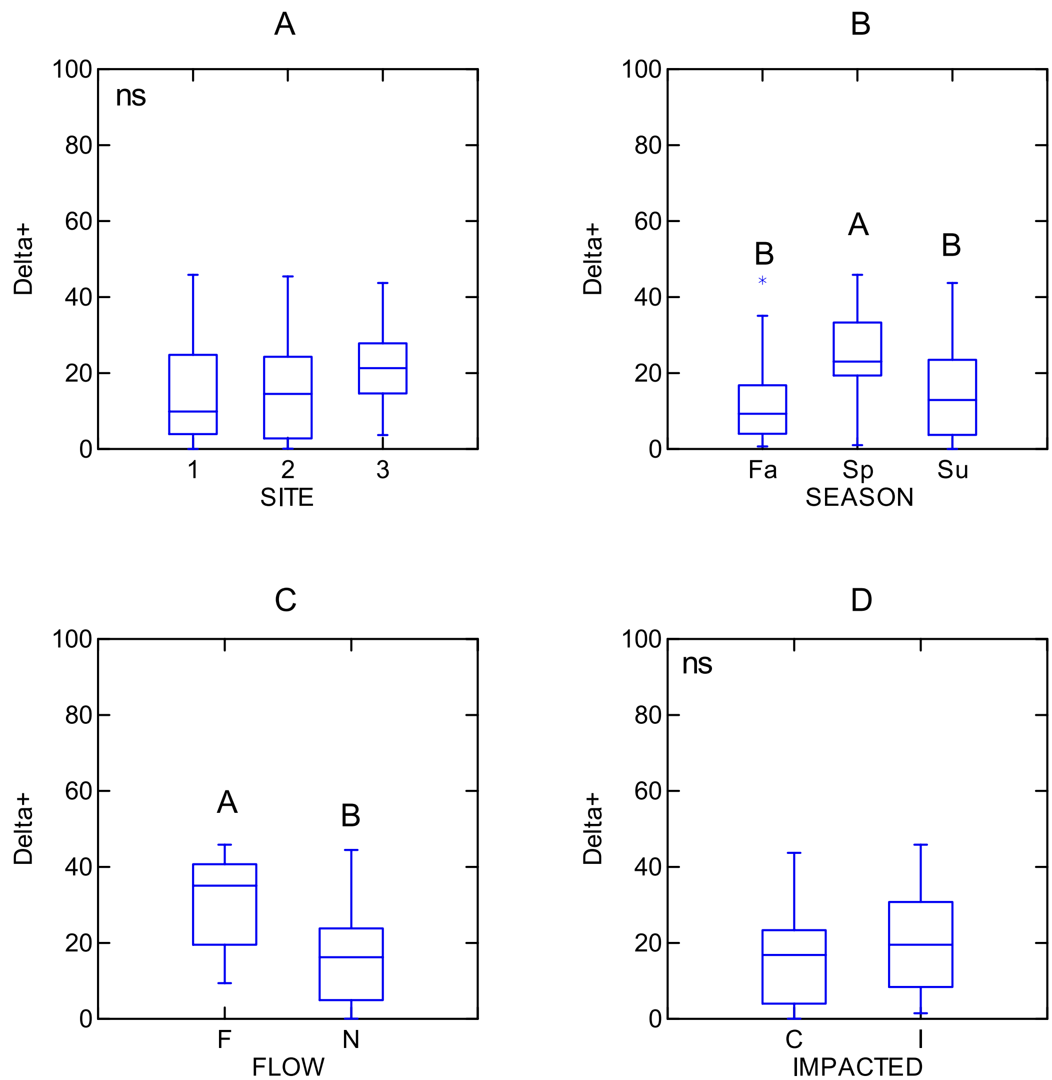


Figure 80. Box plots of Average Taxonomic Diversity values (Delta+) of nekton as recorded by trawl collections from Tres Palacios and Carancahua Creeks. Plot designations follow Fig. 79.

Seasonality was also noted with the trawl collections ($F_{2,67} = 6.258$, $p = 0.003$), although the spring season had the highest degree of diversity with this gear (Fig. 80b). Total abundance was more evenly distributed among a number of genera within a few Families (Clupeidae, Engraulidae, Ictaluridae, and Sciaenidae). Flooding events were characterized by much lower overall abundance, although the taxa collected during these events were usually from a few taxonomically distinct Orders (Clupeiformes and Siluriformes). This lead to an overall increase in taxonomic distinctness (separate variance $t = 3.055$, df = 10.7, $p = 0.001$). As was the case with the bag seines, the impacted stream (Tres Palacios) had a more taxonomically diverse nekton collection than did the reference stream (33 taxa vs. 28 taxa, see Fig. 80d).

Average Delta+ values for the gill net collections revealed that much of taxonomic diversity was recorded at the Order level (mean $\Delta^* = 43.87 \pm 15.42$ SD, see Fig. 81a). Recalling that the gill nets were dominated by a few freshwater taxa [spotted gar (Lepisosteiformes), gizzard shad (Clupeiformes), blue catfish (Siluriformes), and smallmouth buffalo (Cypriniformes)], these taxonomically distant Orders lead to the overall increase in Delta+ values for this gear. Similar to the results obtained with the ANOSIM procedure, no differences were seen in the taxonomic diversity of the gill net collections among the stations (Fig. 81a), seasons (Fig. 81b), or flow conditions (Fig. 81c). The pattern of increased diversity at the impacted stream (31 taxa collected from Tres Palacios vs. 28 taxa collected from Carancahua Creek) was also noted in the gill net collections (Fig. 81d).

Benthic collections were far more diverse than the nekton, with average Delta+ values for both the side collections (mean $\Delta^* = 52.14 \pm 15.39$ SD) and middle collections (mean $\Delta^* = 52.37 \pm 14.65$ SD) characterized by differences at the Class and Order levels (see Figs. 82 and 83). Although overall taxonomic diversity was higher in the benthic invertebrates, no significant differences were detected among the factors of interest for this study (among the sampling stations or seasons, or between the reference and control streams). These results are in agreement with the ANOSIM tests that failed to detect any significant differences among the benthic infaunal collections.

Aquatic invertebrates collected with the D-Frame nets were only identified to the Family level, so the Delta+ values for this group takes on the form of Delta+ = 25 if two individuals drawn at random from a sample are from the same Family; Delta+ = 50, from different Orders; Delta+ = 75; different Class; Delta+ = 100, different Phyla. Diversity values for the D-Frame nets were similar to the benthic collections (mean $\Delta^* = 45.13 \pm 16.26$ SD), ranging mainly between the Class and Order levels. Like the benthic infauna, no consistent pattern of aquatic invertebrate community structure was detected with this analysis (Fig. 84). In all invertebrate collections, average taxonomic diversity was highest in the impacted stream.

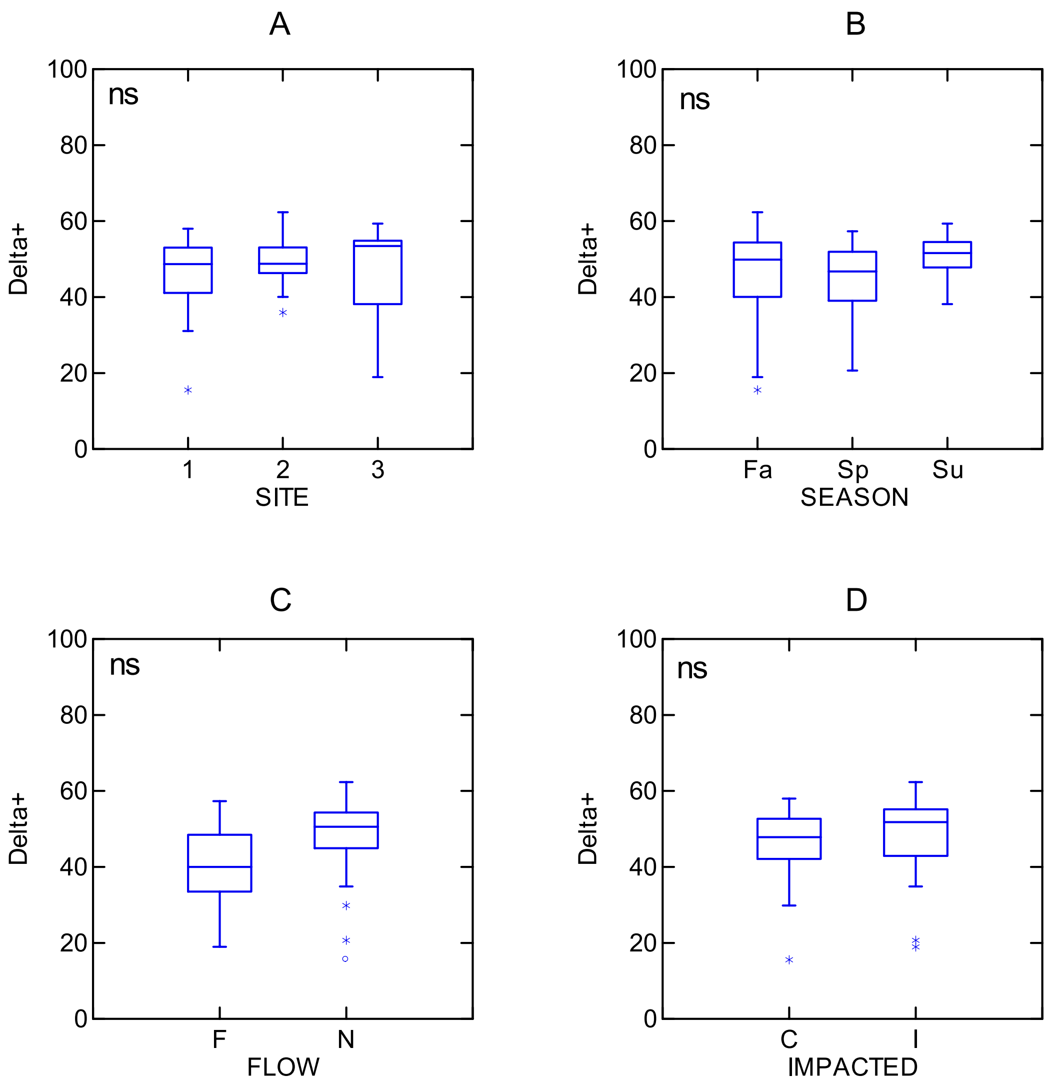


Figure 81. Box plots of Average Taxonomic Diversity values (Delta+) of nekton as recorded by gill net collections from Tres Palacios and Carancahua Creeks. Plot designations follow Fig. 79.

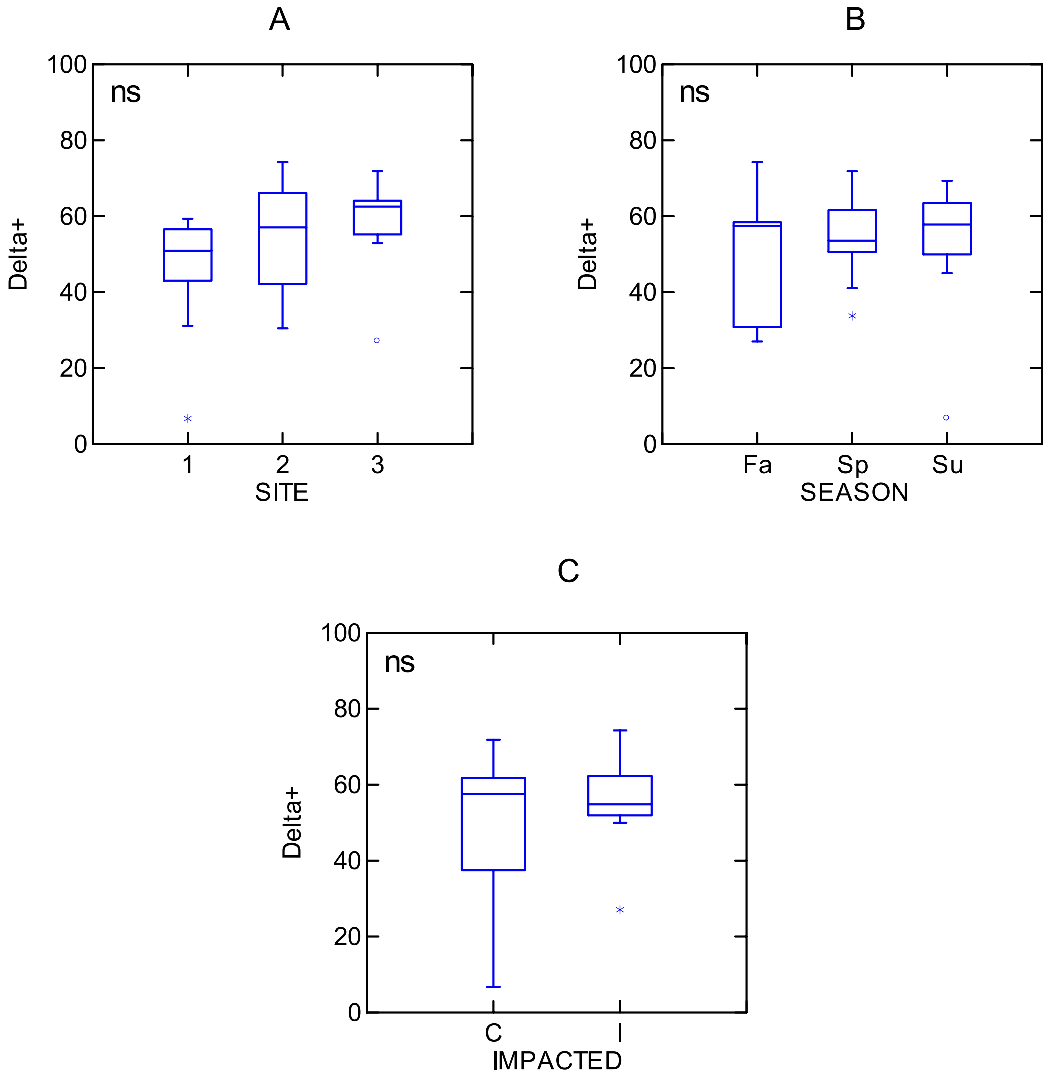


Figure 82. Box plots of Average Taxonomic Diversity values (Delta+) of infaunal invertebrates as recorded by side benthic collections from Tres Palacios and Carancahua Creeks. Plot designations follow Fig. 79, except no flooding condition benthic samples were collected (Plot C in Fig. 79).

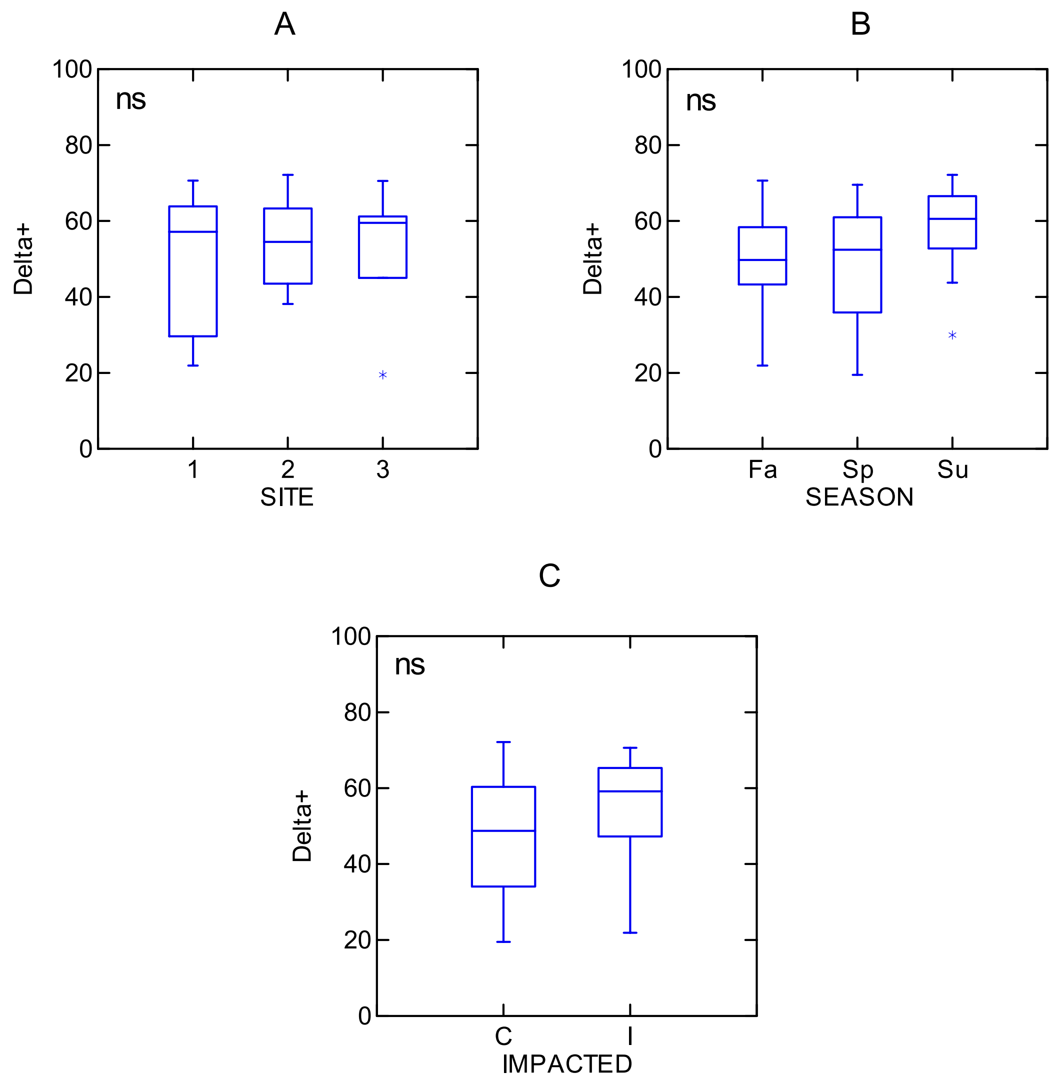


Figure 83. Box plots of Average Taxonomic Diversity values (Delta+) of infaunal invertebrates as recorded by middle benthic collections from Tres Palacios and Carancahua Creeks. Plot designations follow Fig. 79, except no flooding condition benthic samples were collected (Plot C in Fig. 79).

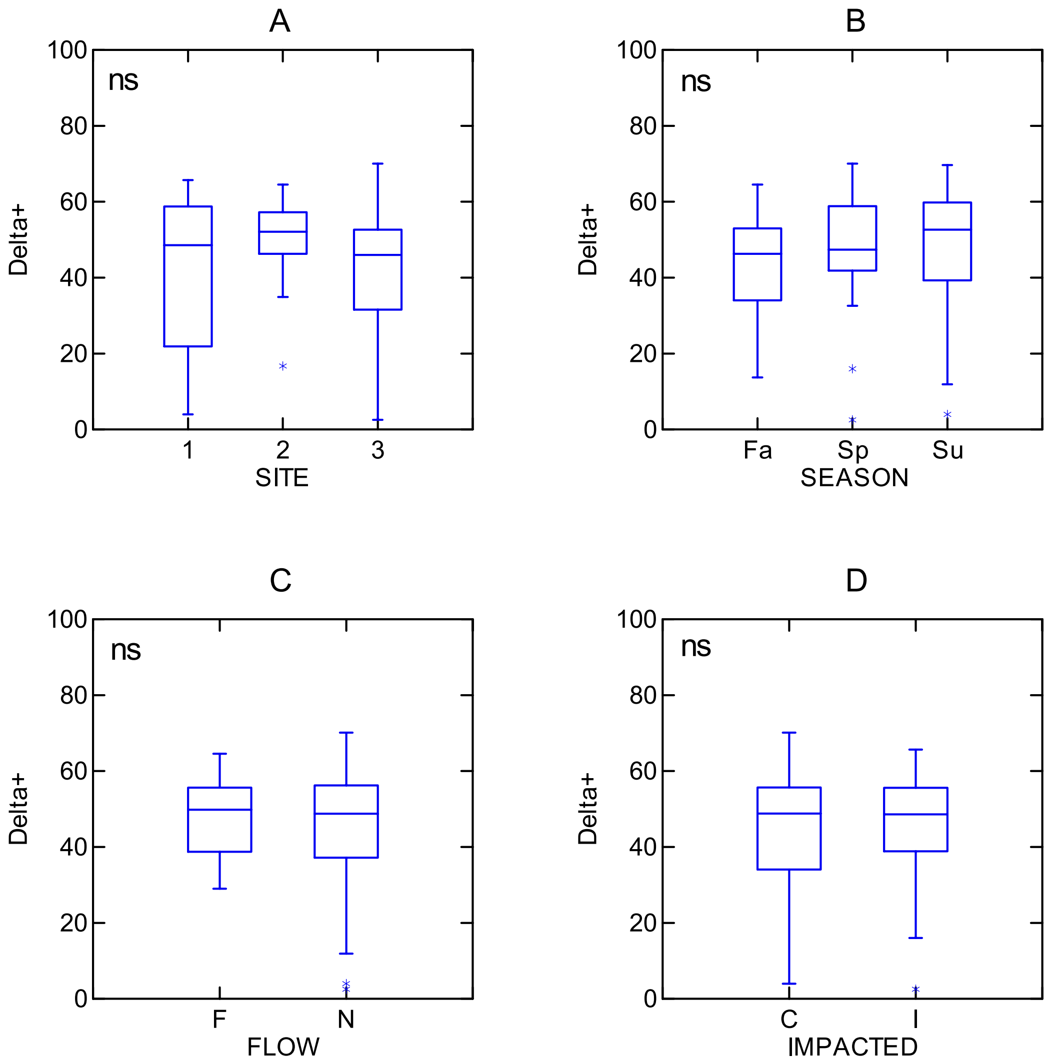


Figure 84. Box plots of Average Taxonomic Diversity values (Delta+) of aquatic invertebrates as recorded by D-frame nets collections from Tres Palacios and Carancahua Creeks. Plot designations follow Fig. 79

Average Taxonomic Distinctness – Garcitas and Carancahua Creeks

Bag seine collections from Garcitas Creek were quite similar in terms of average Delta+ values when compared to Tres Palacios (mean Δ^* = 30.07 ± 21.49 SD, see Fig. 85), with much of the diversity centered around the Family level. The general lack of a salinity gradient along the reach of Garcitas Creek (see Tables 39-41) is also evident in the lack of significant differences in the average taxonomic diversity among the stations (Fig. 85a). This result confirms the overlap of the upper and middle stations, as well as the middle and lower stations that was seen in the ANOSIM procedure (see Nekton Collections – Bag Seines; Fig. 51). Seasonality was also less evident ($F_{2,69}$ = 2.933, p = 0.060), with the summer collections having the highest degree of taxonomic diversity (see Fig. 85b). The lack of any taxonomically-derived seasonality reinforces the dampened seasonal signal found in the MDS configuration presented in Fig. 52a. With bag seines, Delta+ values were not affected by flooding conditions, as the overall diversity of the communities collected during these periods were similar to the reference stream. While Garcitas Creek followed the general pattern of more total species (48 vs. 41 nekton taxa) as well as a more taxonomically diverse nekton collection, these differences were not significant (separate variance t = -1.008, df = 69.1, p = 0.317, see Fig. 85d).

Delta+ values for trawl collections (mean Δ^* = 14.22 ± 14.66 SD) were similar among the sampling stations (Fig. 86a), with the highest degree of diversity encountered during the spring and summer seasons ($F_{2,60}$ = 4.873, p = 0.011). Fall collections were characterized by very high catch rates of bay anchovies and blue catfish, with bay anchovies greatly outnumbering all other taxa thereby lowering the average Delta+ value in this season (see Fig. 86b). The overall similarity in the community structure within Garcitas and Carancahua Creeks, as shown by the means plot MDS ordination (Fig. 54), is confirmed by the range of the Delta+ measure as shown in Fig. 86d. No significant difference in taxonomic diversity was found between the impacted or reference stream.

Similar to the gill net collections from Tres Palacios, average Delta+ values from Garcitas Creek revealed that much of taxonomic diversity was recorded at the Order level (mean Δ^* = 42.03 ± 13.89 SD). The same freshwater taxa that dominated the gill net collections from Tres Palacios [spotted gar (Lepisosteiformes), gizzard shad (Clupeiformes), blue catfish (Siluriformes), and smallmouth buffalo (Cypriniformes)], were also abundant in the Garcitas Creek collections. No significant differences were seen in the taxonomic diversity of the gill net collections among the stations (Fig. 87a), seasons (Fig. 87b), or flow conditions (Fig. 87c). The general pattern of increased diversity at the impacted stream was not as prevalent in the nekton collections from Garcitas Creek, as Delta+ values were lower in Garcitas Creek for both trawls, and gill nets (Figs. 86d and 87d).

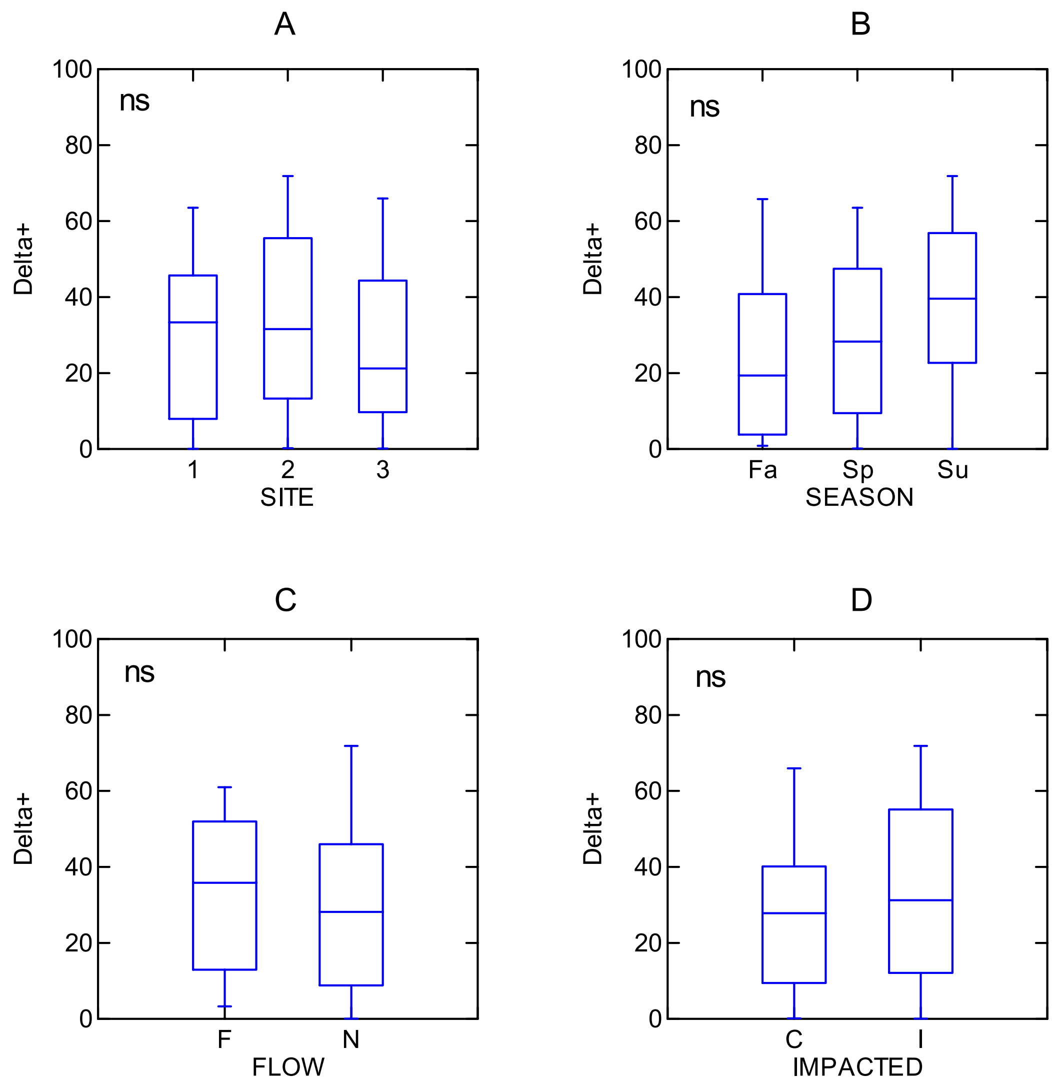


Figure 85. Box plots of Average Taxonomic Diversity values (Delta+) of nekton as recorded by bag seine collections from Garcitas and Carancahua Creeks. A = among Site comparisons (1 = upper, 2 = middle, 3 = lower); B = among Season comparisons (Fa = Fall, Sp = Spring, Su = Summer); C = Flow condition comparison (F = Flood, N = Normal); and D = Impacted comparison (C = control – Carancahua Creek, I = Impacted, Garcitas Creek). Categories within each plot with the same letter are not significantly different (test results and probability levels for each significant difference reported in the text). No significant difference identified by ns.

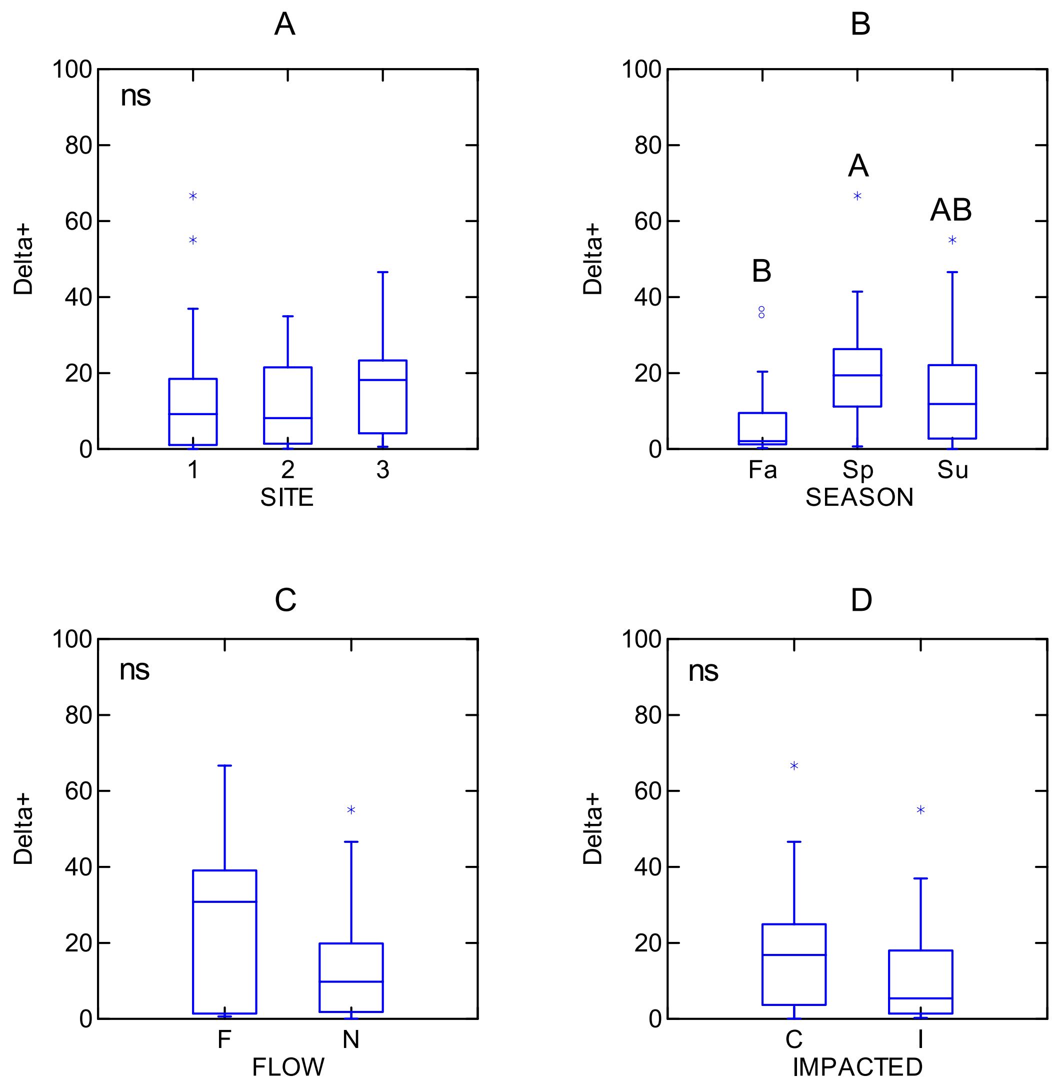


Figure 86. Box plots of Average Taxonomic Diversity values (Delta+) of nekton as recorded by trawl collections from Garcitas and Carancahua Creeks. Plot designations follow Fig. 85.

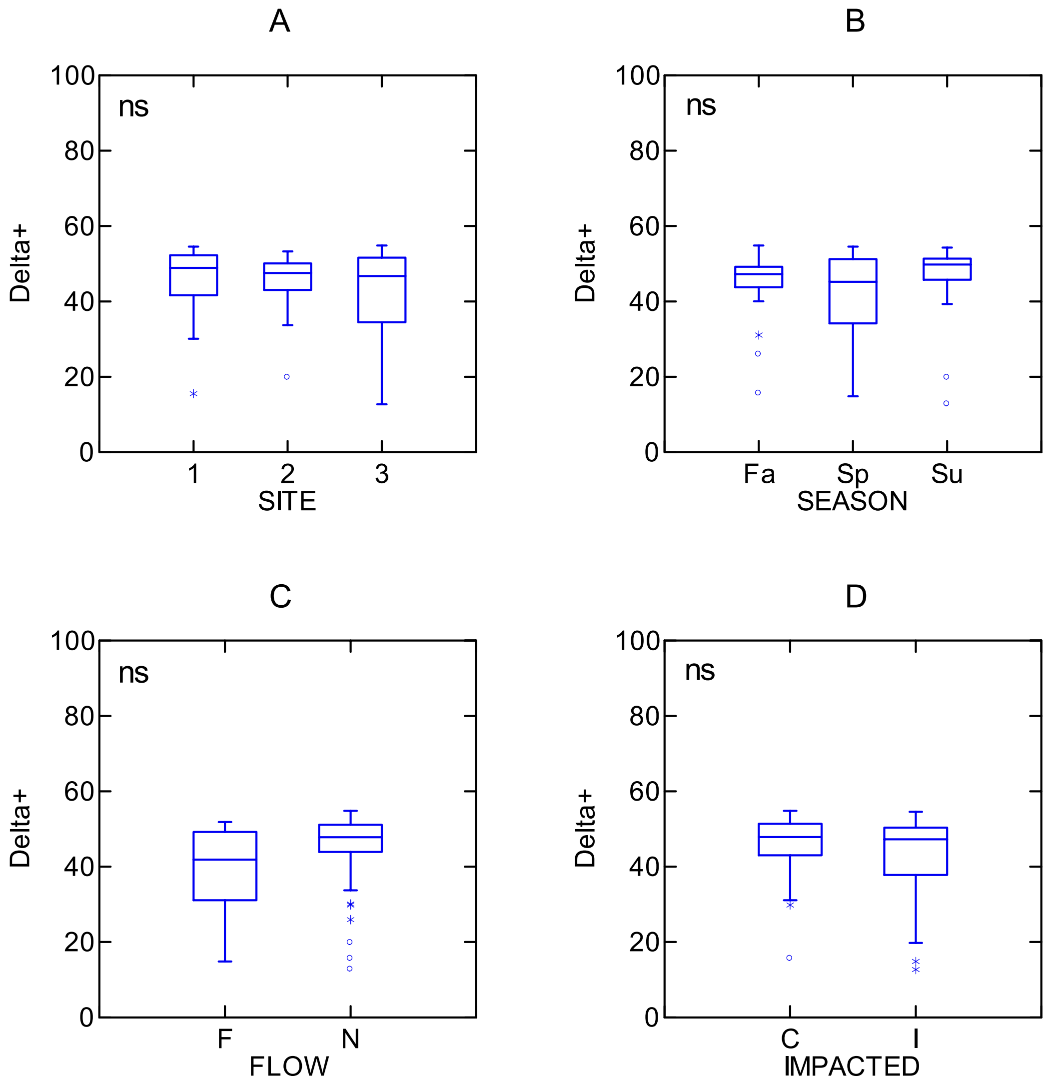


Figure 87. Box plots of Average Taxonomic Diversity values (Delta+) of nekton as recorded by gill net collections from Garcitas and Carancahua Creeks. Plot designations follow Fig. 85.

Benthic infauna were again much more diverse than the nekton assemblages, with average Delta+ values for both the side collections (mean $\Delta^* = 51.78 \pm 17.98$ SD) and middle collections (mean $\Delta^* = 49.79 \pm 19.35$ SD) characterized by differences at the Class and Order levels (see Figs. 88 and 89). While far more taxa were encountered in the benthic invertebrate collections, no significant differences were detected among the factors of interest for this study (among the sampling stations or seasons, or between the reference and control streams). While not significant, the benthic infauna followed the pattern seen in the nekton, in that diversity tended to increase from the upper to the lower stations, with the most diverse collections encountered at the lowermost station (see Figs. 88a and 89a).

Diversity values for the D-Frame net collections from Garcitas Creek were generally characterized by Class and Order level distinctions (mean $\Delta^* = 45.13 \pm 16.26$ SD). Unlike the collections from Tres Palacios, consistent patterns of aquatic invertebrate community structure were detected with this analysis (Fig. 90). The middle and lower stations had significantly higher taxonomic diversity ($F_{2,67} = 3.705$, $p = 0.030$), in addition to the spring and summer seasons being more taxonomically rich ($F_{2,67} = 5.295$, $p = 0.007$, see Figs. 90a and 90b). Average taxonomic diversity was highest in the impacted stream in all invertebrate collections.

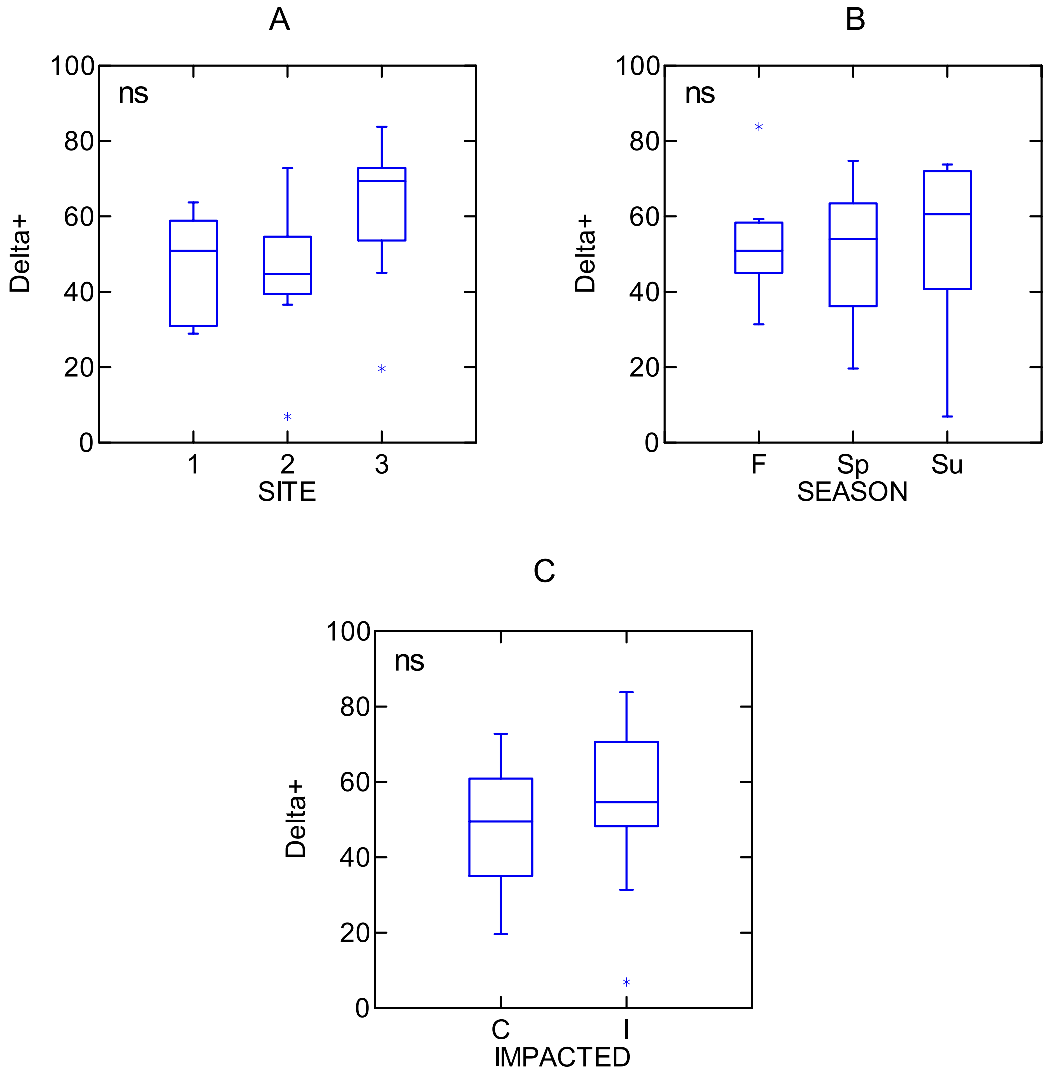


Figure 88. Box plots of Average Taxonomic Diversity values (Delta+) of infaunal invertebrates as recorded by side benthic collections from Garcitas and Carancahua Creeks. Plot designations follow Fig. 85, except no flooding condition benthic samples were collected (Plot C in Fig. 85).

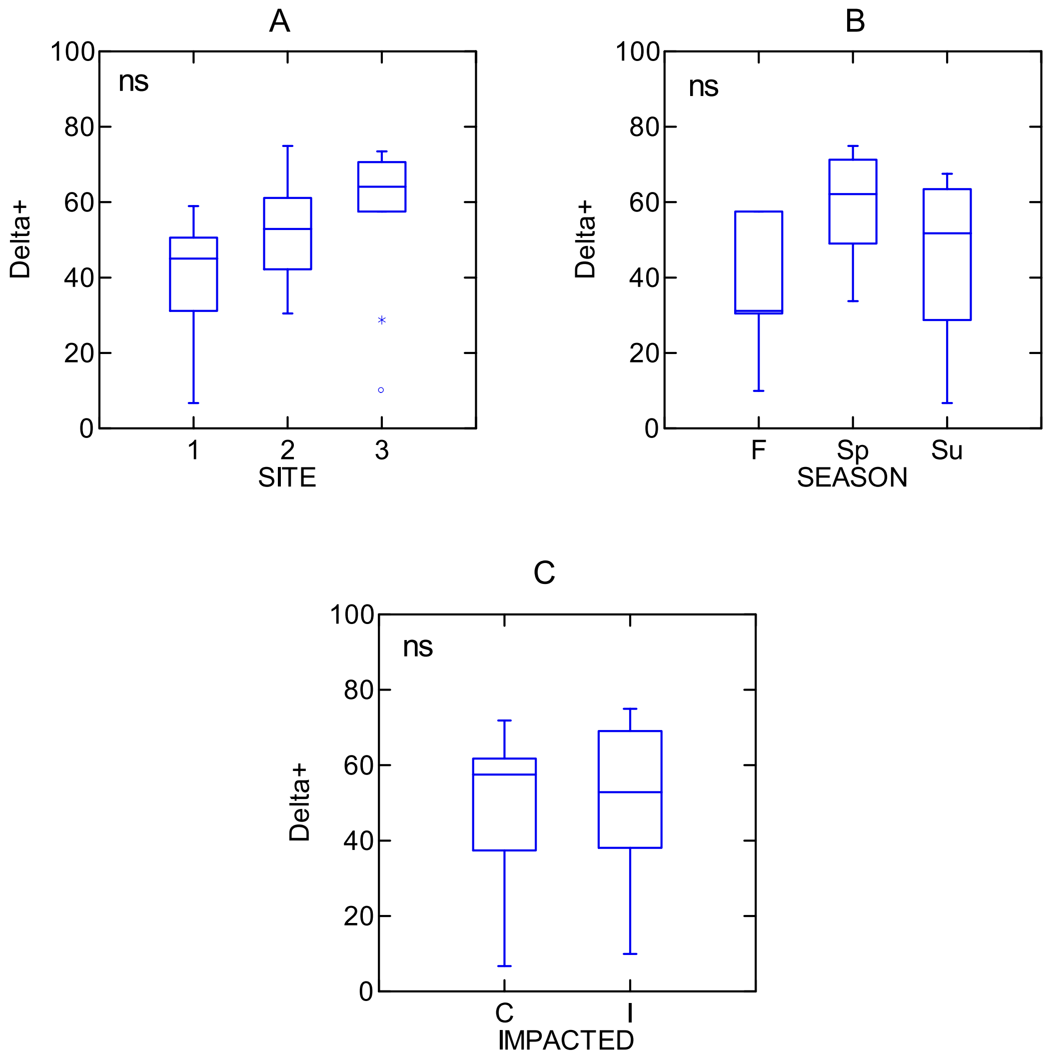


Figure 89. Box plots of Average Taxonomic Diversity values (Delta+) of infaunal invertebrates as recorded by middle benthic collections from Garcitas and Carancahua Creeks. Plot designations follow Fig. 85, except no flooding condition benthic samples were collected (Plot C in Fig. 85).

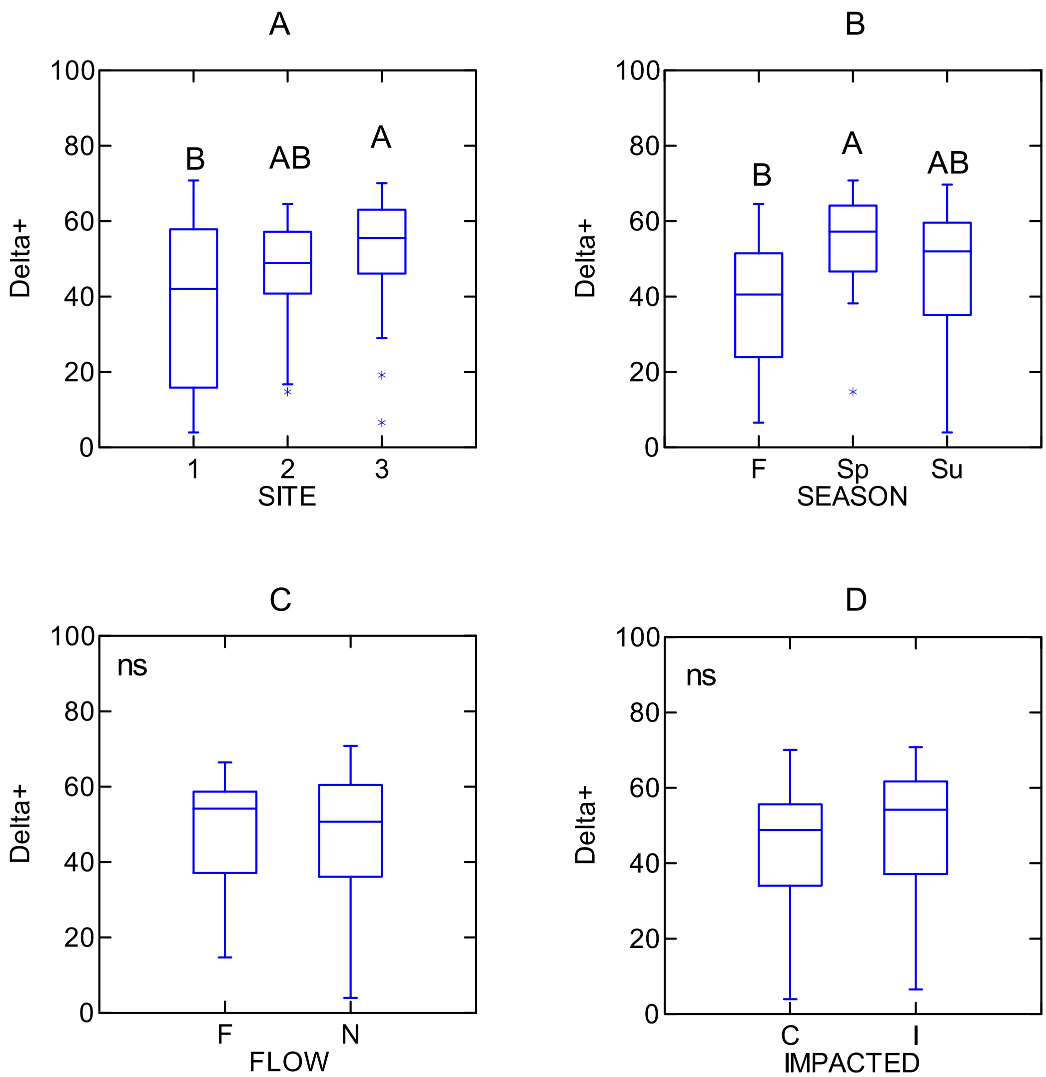


Figure 90. Box plots of Average Taxonomic Diversity values (Delta+) of aquatic invertebrates as recorded by D-frame net collections from Garcitas and Carancahua Creeks. Plot designations follow Fig. 85.

DISCUSSION

Naturally occurring differences among surface water in physical habitat structure and associated hydraulic characteristics contributes to much of the observed variation in species composition and abundance within a zoogeographical province (Averill and Peck, 1999). The initial task of this study was to determine whether any differences in the physical, chemical, or biological components of the ecosystem could be found between the reference stream and each of the study streams. The null hypothesis in all tests took on the form of "conditions within the study streams are the same as the conditions within the reference stream". All test statistics were then evaluated with respect to the null, in that it represents the status quo and should not rejected unless the sample results strongly imply that it was false. Previous works using these same components of ecosystem health in order to assign a categorical "aquatic life use" to a particular waterbody have normally relied on univariate methods which may not fully integrate the synergistic (or antagonistic) effects of these variables (Michael and Moore, 1997; Davis, 1998; Bayer, 2000). This study introduces a new assessment methodology, which relies heavily on multivariate ordination techniques, to integrate the many disparate physical, chemical, and biological components of ecosystem health and allows for robust comparisons of tidally influenced systems. The results of this study will ultimately be used to help make recommendations regarding the appropriate aquatic life uses currently identified for classified as well as the numerous unclassified tidal streams in the State of Texas.

The following presents the results from the sampling program conducted from March 2003 – November 2004 on the tidal portions of Tres Palacios, Garcitas, and Carancahua Creeks. Results will be discussed in the context of the major ecosystem health components measured: physical (landcover and land use, instream and riparian habitat, and instream flow), chemical (transitory and synoptic water quality, water and sediment chemistry), and biological (nekton assemblages, benthic invertebrate assemblages, and aquatic invertebrate assemblages).

Landcover and Land Use Classification

Tres Palacios

Tres Palacios River has 12.3% more agriculture than Carancahua Creek and a watershed three times larger. Tres Palacios also has a higher percentage of grassland (5%). These two classes are potentially large contributors to the nutrient and sediment loads in the stream system. Half of Tres Palacios River watershed is agriculture. The potential inputs to the system from agriculture will probably overwhelm all other inputs. Grassland in this system, along with the shrub classes, is mostly grazing land, usually with much lower inputs of fertilizer and other chemicals but still potentially high input of nutrients from manure. Some percentage of the live oak forests in both watersheds is low intensity residential development, mostly weekend/vacation properties.

The buffer analysis shows a larger potential for impact from agriculture as Tres Palacios buffer has 34% more of the buffer in agriculture. This means that there is very little, if any, area that can buffer the impacts from agricultural activities. Much of the runoff from agriculture in Tres Palacios goes directly into the stream. Carancahua Creek has more grazing land use classes adjacent to the stream; these lands will absorb some of the sediments and excess nutrients from agricultural practices and buffer the stream from these impacts. However, there is some increased potential for impact from residential development within the Live Oak Forest class. The larger relative amount of live oak forest in the Carancahua Creek watershed adjacent to the stream may be offset by lower development density given the increased distance from the Houston metropolitan area.

Carancahua Creek watershed, on average, receives less rainfall, and has less irrigation infrastructure. This leads to more grazing and less agriculture; also most of the agriculture in the Carancahua Creek watershed is dry-land farming, mostly small grains and cotton, whereas Tres Palacios agriculture has a large percentage of rice farming. Much of this runoff is drained directly to Tres Palacios River and its tributaries, without buffering by other land cover classes. This will increase the relative impact of agriculture, thus increasing the true impacts beyond the actual differences in area in agriculture.

Urban index analysis for each basin indicates that density of development may be less and / or impacts from other sources, such as agriculture, may be more important in explaining differences in stream quality.

Garcitas

Garcitas Creek watershed and Carancahua Creek watershed are very similar; there is about 5% more agriculture in the Carancahua Creek watershed though in major absolute terms, Garcitas Creek has more area in agriculture. There is also slightly more live oak forest in Garcitas Creek watershed. There are some differences in the structure of the vegetation in classes primarily used for grazing (grassland and shrub), mainly the replacement of evergreen shrubs in Carancahua Creek with mesquite – huisache shrubland in Garcitas Creek watershed. There is more grassland in Garcitas Creek watershed which may allow faster runoff in to the stream and more sediment to get into the stream. Cold-deciduous shrubland is mostly present in Carancahua Creek watershed, this land is used for grazing, along with the grassland class, and is likely to be more heavily managed pasture and hence may have more nutrient runoff.

The buffer analysis may provide more insight into potential impacts to the stream system; even though the percentage of live oak forest for both watersheds is basically the same (1.2 % more for Carancahua), there is 9.3 % more live oak forest within 200 meters of the center of Garcitas Creek. Given that this landcover is prone to development, this may increase impacts to the stream. Garcitas Creek also has more grassland within 200 meters of the stream. Since the grassland class is primarily improved pasture and hay fields, this cover class could also have a larger impact to water quality in the stream.

The similarity of the two watersheds is again reflected in the small differences in relative amounts of high urban index scoring areas. Differences in water quality are most likely from other causes than differing industrial / residential development.

Instream and Riparian Habitat Classification

Tres Palacios River and Garcitas and Carancahua Creeks

All three streams had similar thalweg pattern as might be expected since none of them appear to have experienced much if any channelization or dredging. All three streams showed a decrease in their respective maximum depths at their lowest reaches. The streams became shallower and wider at their lower ends. This may be due to the increased tidal nature of their lowest reaches. With flows alternately traveling up and down these streams at these locations, sediments would be expected to fall out of suspension and accumulate due to decreased flow velocities and variable direction of flows. The same factors may have operated to cause the gradual shallowing along the sides of the streams at their downstream reaches.

The slow flowing nature of Texas tidal streams was apparent in the stream habitat data, as well. The streams were characterized as pools or glides at all their sampling reaches. These streams pass through very flat coastal landscapes, so there are no instances here where water flows down any significant gradient such as a riffle or rapid in the study reaches. Thus the low stream gradients and relatively flat watersheds associated with them resulted in only calm flowing stream habitat types in the reaches sampled.

The high amount of sand in Carancahua and Garcitas and fine materials in Tres Palacios are likely a reflection of their respective local source materials, the soils in the watershed and immediate buffer areas. However, the high relative percentages of gravel and or cobble found along the bottoms of these streams was surprising. Retrieval of a sample of this material from the bottom of Tres

Palacios River revealed that at least some of it was comprised of concretions (Nathan Kuhn, personal observation) possibly of redoximorphic origin. However, it also is highly likely that at least some of this material was composed of shell materials, rock, or caliche nodules (White et al. 1988).

Channel width increased and bank incision (and bank angle) decreased in all streams from upper to lower reaches. These measurements are typical of most rivers and streams (Rosgen 1996). Areas lower in the watershed receive more water, thus requiring a wider channel in order to conduct those materials (water and sediments) to their eventual destination in the bay and peripheral wetlands. Incision was likely greater in the upper reaches because the more woody vegetative cover found there (see below) would better hold sediments and resist erosive forces during flooding thus confining flows and erosion to the stream channel itself.

Vegetation followed a similar pattern in all streams, with woody materials, especially trees, being dominant in the upper reaches and herbaceous species and low growing shrubs dominating the lower reaches. This is a reflection of the increasing influence of salt and tides in the lower reaches of both streams and is generally typical of the entire Texas coast. Since there are no endemic tree species adapted to surviving higher salinities in this part of Texas, this cover component falls out of the vegetative measurements at the lower reaches and is replaced by more salt tolerant herbaceous and woody marsh species to some degree. The edges of both streams generally appeared to transition from a riparian forest wetland community in their upper reaches to a salt marsh wetland community at their lower reaches.

All three streams had more in-channel fish cover in their upper reaches than in their lower ones. This was due mainly to a decrease in the amount of woody material (i.e., trees) present in-stream as well as along the immediate stream edges in lower stream reaches. However, this does not necessarily indicate that these lower reaches were poor fish habitat. Many parts of the lower portions of each stream were edged by thick macrophyte cover along their borders, which provide quality fish cover. Furthermore, as revealed in the land cover analysis section, portions of these lower reaches, not directly measured by the instream and riparian habitat classification study, were composed of marsh wetlands, which are excellent fish habitat.

Indicators of human influence in these three streams appear to be dominated mainly by agriculture. A review of the land cover analysis section for these streams reveals that a sizable portion of their respective watersheds are devoted to agriculture, pasture, and/or grazing. Human influences attributable to direct human habitation were less frequently observed, likely because these areas are relatively less populated parts of the Texas coast.

Instream Flow Characterization

The coastal streams studied are small, with limited channel inputs between stations. Flow within streams and at particular stations is highly variable over time. Flows were generally lower in April and August at all sites. However, infrequent events (as in September 2003 and May 2004) can result in extremely high levels of stream discharge that exceed by 20 to 40 times the lowest recorded measures. Although during these events all study sites (upper, middle and downstream reaches) on a particular stream increase in flow, generally, flows at upstream and middle stations are nearly half of the measured flows at the downstream station.

For the mid-coast region, mean flow was highest in the Tres Palacios River. For all study streams, tidal influence in the middle reaches was documented by characteristic oscillations in the direction and magnitude of flow. This oscillation pattern was present during most sampling events indicating regular tidal influence. There is no similarly recorded information for the upstream and downstream stations. However, tidal influence was expected to be relatively greater at downstream sites. For the upstream sites, tidal influence was expected to be weaker. Because the relative contribution of tidal currents depended on downstream discharge, strength of the tidal cycle and river morphology, under low flow conditions or during a weak tidal cycle, upstream stations may not be influenced by tides.

The narrow width and shallow depth of the study streams, combined with the ameliorating effects of the bays and estuaries, decrease the likelihood that tidal currents will create a salt-wedge and hence bi-directional flow within the water column. However, the absence of bi-directional flows in the study streams does not indicate a lack of tidal impact, but rather the absence of a distinct layer of freshwater overlying saltwater within the water column at sites in the middle reaches of these study streams during the periods of observation. Tidal impact to flow was evident in the varied estimates of stream discharge obtained from replicate transects (ADCP data) during sampling events.

Water Quality Characterization

Transitory Water Quality

Overall water quality was not markedly different between either of the study streams and the reference stream, with salinity and dissolved oxygen being the variables most responsible for any differences noted. Along the entire reach of each stream, salinity values ranged from very fresh in the upper stations to brackish in the lower stations, with the salinity gradient along each reach greatly mediated by the presence or absence of flooding conditions. The influence of tidal flows was most evident on Tres Palacios Creek, with the difference in salinity along this reach ranging on the order of 10 PSU. While the ANOSIM procedure found a significant difference in water quality on Tres Palacios when compared to the reference stream (the lower station was different from the upper and middle stations, see Fig. 16), this difference was mirrored within the reference stream. The low Global R value of this test (R = 0.132) is indicative of a high degree of variability, and this variability is reinforced in Fig. 14a. The lower stations on both Tres Palacios and Carancahua Creek are scattered throughout the MDS plot, with lower salinity conditions much more prevalent in the reference stream (see the salinity overlay of the water quality MDS configuration shown in Fig. 15b). No significant difference in water quality was found between Garcitas Creek and the reference stream.

Vertical depth profiles of field measurements (temperature, pH, dissolved oxygen, and salinity) collected from 0.3 m below the surface, 0.3 m above the bottom, and at stations with sufficient depth, halfway between the surface and the bottom readings, revealed the presence of water column stratification in each study stream. Generally, salinity increased with depth, and dissolved oxygen decreased with depth. While salinity varied with depth (increasing 4 – 6 PSU from the surface to the bottom, depending on flow rates), dissolved oxygen showed the greatest degree of variability. Surface waters were generally more saturated than were either the mid- or bottom-water measurements, with hypoxic and at times anoxic conditions encountered in the bottom waters on each study stream. Low dissolved oxygen conditions were noted most often from Carancahua Creek, with bottom water measurements from the upper and middle stations (WC 1 and WC 2) within this reference stream averaging dissolved oxygen readings < 3 mg/L (Table 37). Low dissolved oxygen conditions were not as prevalent at the lower stations on any of the streams sampled for this study (TP 3, WC 3, or GC 3).

Synoptic Water Quality

Dissolved oxygen concentration in an aquatic ecosystem is a function of both the biotic (living) and abiotic (non-living) components. Major biotic components include photosynthesis, the production of sugars and other organic molecules by photoautotrophs using the energy from sunlight, and respiration, the breakdown of these same molecules by heterotrophs for energy (Montagna and Russell, 2003). Abiotic components have both direct and indirect effects on dissolved oxygen concentrations. Temperature, salinity, and pressure all affect the solubility of oxygen in water. Interactions between the biotic and abiotic components that regulate dissolved oxygen concentration are highly dynamic spatially and temporally. Instantaneous grab samples (like those of the water quality profiles previously discussed) may not fully capture the dynamic nature of water quality at a given location. TCEQ therefore has established DO criteria based on a 24-hr average that varies with the aquatic life designation of a water body. The criteria for exceptional aquatic life require minimum 24-hr DO measurements to be greater than 4 mg/L and average 24-hr DO measurements to be greater than 5 mg/L (see Table 1).

Multiprobe datasondes were deployed at each fixed sampling location in order to collect a full diurnal set of field parameter measurements. While dissolved oxygen was the primary focus of the datasondes, sampling all the water quality parameters over a full diurnal cycle allows for a better understanding of temporal variability. Sampling locations for the datasondes were approximately 0.3 m below the surface, so conditions recorded with these instruments were more like those of the surface grab samples. Similar to the profile measurements, the ANOSIM procedure failed to detect any difference in synoptic water quality between the study streams and the reference stream. This is not to say that there were no differences among the stations on each stream, as minimum and average salinity, dissolved oxygen, and temperature were clearly different between the upper and lower stations on each study stream (see Tables 43 and 45).

To better understand the lack of significant differences identified with the ANOSIM procedure, return to the principal components analysis of the datasonde deployments. In each case (Tres Palacios, Table 44; and Garcitas Creek, Table 46), the combination of the 24-hr average dissolved oxygen, average specific conductance, and average temperature measurements essentially separated the sampling events along a seasonal gradient. The spatial extent of these seasonal conditions (relatively cooler water temperatures with higher dissolved oxygen values in the spring and fall; warmer waters and lower dissolved oxygen in the summer) is captured in Figs. 21a and 24a. The dynamic role of salinity as one of the abiotic factors controlling surface water dissolved oxygen levels can be found in the component loadings along the second principal component for both Tres Palacios (PC2 loading = 0.657, Table 44) and Garcitas Creek (PC2 loading = 0.888, Table 46). With the stations arranged on a seasonal basis, there was a mixture of upper, middle, and lower fixed sampling stations (TP 1, TP 2, and TP 3, for example) within the principal component analysis ordination (see Fig. 21a). This temporal-based mix of sampling locations leads to the result of no difference among the stations with the ANOSIM procedure (Figs. 22 and 25).

Using the criteria for exceptional aquatic life use as the basis for comparison (minimum 24-hr DO measurements greater than 4 mg/L and average 24-hr DO measurements greater than 5 mg/L), Tres Palacios Creek failed to meet the 24-hour minimum DO requirement 57.1 % of the time (8 out of 14 deployments). The average 24-hour DO requirement was also not met 42.8 % of the time (6 out of 14 deployments). Conditions at Garcitas Creek were quite similar, in that the DO requirements for a “High” waterbody (24-hour minimum > 4.0mg/L) was not met 54.2 % of the time (13 out of 24 deployments) and the average 24-hour DO requirement (> 3.0 mg/L) was not met 45.8 % of the time (11 out of 24 deployments). Underscoring the difficulty in finding a suitable, relatively unimpacted coastal reference stream, the 24-hour minimum and average DO conditions on Carancahua Creek were equally depressed. Minimum DO requirement were not met 52.6 % of the time (10 out of 19 deployments) and the average 24-hour DO requirement was not met 57.9 % of the time (11 out of 19 deployments). On each stream, the majority of the exceedance values were found at the upper and middle stations. Low dissolved oxygen values were not that common from any lower sampling station on any of the study streams. The preceding analysis included datasonde deployments covering all sampling seasons, not just the summer critical index period (Jul 1 – Sep 30; TCEQ, 2000a). Had the data been limited to the summer period only, minimum and average DO requirements would have not been met 100 % of the time on both study streams as well as the reference stream.

Water and Sediment Chemistry

Analysis of the water quality data, with respect to both a transitory and a synoptic frame of reference, revealed that inflows (as measured by the field parameters of salinity and specific conductance) were the variables most responsible for structuring the physical realm of the aquatic environment in each of the study streams. Treatment of the water chemistry data by similar techniques also revealed that proxies for inflow (e.g., chloride, fluoride, nitrite, and alkalinity) were highly influential in determining the placement of stations in both PCA ordinations (see Figs. 27 and 34) and MDS space (Figs. 28 and 35). This overriding role of inflow, especially the extreme inflow events as measured during flooding conditions, adds a tremendous amount of variability to the data. It is therefore not surprising that the ANOSIM procedure failed to detect any significant difference in either the water quality or the water chemistry among within stations on a common streams (Figs. 28a and 35a) or between the study and the reference stream (Figs. 28b and 35b).

Even flows far less than extreme flooding events can still be quite instrumental in structuring the chemical components of the aquatic environment characteristic of tidally influenced systems. As stated in the Surface Water Quality Monitoring Manual (TCEQ 1999a), “water quality in small and medium streams and in the headwaters of many reservoirs is influenced by runoff during and immediately after rainfall events. This influence is site specific and poorly studied”. For this study it was determined that, instead of avoiding recent rainfalls and post-rainfall flooding conditions, we would attempt to collect all the physical, chemical, and biological parameters during these anomalous conditions in order to better understand the role of inflows across a full range. From the results presented in Figs. 27b and 34b, it is clear that these flooding events are dramatically different in terms of the inflow proxy parameters (chloride, fluoride, nitrite, and alkalinity) identified as important in the analysis. Positively associated with these inflow events were parameters like phosphorus, total organic carbon, and total Kjeldahl nitrogen; potential tracking land-based runoff loading into each streams ecosystem. The overall effect of these floods (and even lower volume “high flow” events) it to reset the aquatic environment along the entire reach of the stream to chemical constituent levels that are essentially uniform from upper, middle, and lower stations (recall the mixture of stations in the MDS ordinations of Figs. 28a and 35a). Any physically-mediated differences in water chemistry or water quality (either vertical stratifications or along-stream gradients) are then lost within the system as a result of these flow conditions. The physical and chemical “clock” of the ecosystem is reset to zero (i.e., freshwater conditions) for the entire length of the tidal portions of the ecosystem. How quickly each system returns to “tidally influenced” depends upon the physical drivers responsible for moving saltwater back into the river portions of the estuary (compare Garcitas and Carancahua Creeks in Fig. 35b, recalling that a greater salinity gradient existed on Garcitas Creek, thereby elongating the sampling locations on Garcitas Creek in the x-axis dimension in this Figure).

The physical role of these flooding events was also evident in the sediment collections, as the composition of the sediments ranged from high in silts and clays to mostly sands within the same sampling location over the two years of this study (for an example, see the configuration of WC 1 in Fig. 30). With each flood event, the physical scouring of the bottom (as well as the sides) of the channel dramatically changed the composition of the sediments. With this degree of variability, it is no wonder that the ANOSIM procedure failed to find any consistent patterns in the sediment constituents. This same analysis also revealed that the composition of the sediment could be dramatically different between the side and the middle of the stream within the same station.

Within Garcitas Creek, the upper and middle stations (GC 1 and GC 2) were significantly different from the lower station, and the lower station on Garcitas Creek was quite similar to each of the stations sampled on the reference stream (Fig. 40). This result is partly due to the surrounding geologic formation, as Tidwell and Davis (1989) reported the bottom substrates within Garcitas Creek were nearly uniform, consisting primarily of sand (their Station D is in nearly the same location as the upper station used for this study, GC1). On the Land Resource Map of Texas (1999), the upper portions of Garcitas Creeks runs through areas designated Rs1 (major recharge sand, some gravel; high permeability; stable, vegetated slopes in rolling hills to flats), while the lower section of Garcitas Creek drains areas designated C1 (expansive clay and mud – locally silty, locally calcareous; flat to low, hilly prairie; locally tilled). All of Tres Palacios, as well as Carancahua Creek, are within the Rs3 zone (secondary aquifer recharge – sand with mud; moderate permeability; variable topography), which is substantially different from the Rs1 zone. The geological makeup of the upper watershed on Garcitas Creek could be the factor leading to the consistent elevated sand compositions of the sediments found in GC 1 and GC 2, even after flooding events reworked the channel’s sediment composition.

Nekton Assemblages

The distribution and abundance of nekton species, and thus community similarity, varied spatially and seasonally along the gradient from freshwater tidal to mesohaline sites. Dramatic differences in the community composition between the impacted streams (Tres Palacios Creek and Garcitas Creek) and the reference stream (Carancahua Creek) were generally lacking. The greatest changes occurred in response to seasonal changes in water temperature and salinity, as variations in rainfall and river flow altered the position of the higher salinity zones within each stream reach. A variety of highly euryhaline/marine taxa (Clupeidae, Engraulidae, Sciaenidae, Penaeidae, Paleomonidae, Portunidae) numerically dominated the nekton collections, and these same taxa are numerically abundant in estuaries all along the Gulf of Mexico and Atlantic coasts (Rozas and Hackney, 1984; Fremling et al., 1989; Peterson and Ross, 1991; Baltz et al., 1993; Ogburn-Matthews and Allen, 1993). Many of the estuarine forms that used the tidal freshwater and olioghaline habitats within the study streams were collected at post-larval and juvenile stages, suggesting that each of the streams is serving important nursery functions for the fisheries of Matagorda Bay.

Differences in overall nekton community composition were far more affected by salinity than any other physical or chemical parameter measure, irrespective of the season of collection. The agreement of the MDS configurations between the biotic and abiotic components of the ecosystem was driven by salinity-related distributional differences (see Fig. 74 for an example). The presence of seasonality, which was also noted in the water quality collections (spring and fall seasons being similar, and the summer season spanning the MDS ordinations; see Figs. 14b and 18b for examples), was again quite prevalent in the nekton collections. The strength of this seasonality factor was gear-dependent, as the bag seines and trawls recorded very distinct seasonal communities, while the gill nets sampled essentially the same community across all seasons (compare Figs. 43a and 46a to Fig. 49a). Within each stream, the lower-most stations were typically the stations responsible for any significant differences seen in the nekton communities, with many marine forms far more abundant in the lower reaches (e.g., sand trout, red drum, Atlantic croaker, grass shrimp, and spot). Despite sampling very different portions of the tidal reach, the bag seines (side of the stream, near-surface collections; young-of-the-year and juvenile stages) and trawls (middle of the stream, near-bottom collections; juvenile and sub-adult stages) recorded very similar communities (highly significant correlations between the MDS configurations of these two gears; see Tables 73 and 74). These gears were dominated by marine/estuarine forms: gulf menhaden, bay anchovies, blue catfish, Atlantic croaker, white shrimp, and brown shrimp. On the other hand, the gill nets (near-surface to near-bottom, sampling across the entire width of the stream; sub-adult to adult stages) were dominated by freshwater taxa (spotted gar, gizzard shad, blue catfish, and smallmouth buffalo), and generally lack the distinct seasonal signature of the other two nekton gears.

The expression of an estuarine species minimum, or a species richness minimum occurring near oligohaline salinities (Remane and Schlieper, 1971), is thought to be linked to the extreme biological, chemical, and physical changes that are most prevalent in low salinities (<10 PSU). These physiological stressors effectively limit the numbers of resident faunal taxa found in oligohaline environments (McClusky, 1971; Day et al., 1989). While this general feature of the estuarine gradient has been primarily associated with the distribution of benthic macroinvertebrates (Gainey and Greenburg, 1977; Wolff, 1983; Diaz, 1989), studies along the Gulf of Mexico and Atlantic coasts have generally confirmed the rise in the number of fish species along transects from mesohaline environments to nearshore environments (Gunter, 1961; Dahlberg, 1972). Studies focusing on the lower salinity oligohaline environments have been equivocal, with some studies noting a species minimum present (Rogers et al., 1984; Wagner, 1999) to others failing to detect a discrete minimum (Peterson and Ross, 1991; West and King, 1996). Similar to the equivocal nature of this phenomenon in the literature, we found that the expression of this estuarine species minimum appears to be gear-specific, with a minimum in richness values in lower salinity conditions more pronounced in the trawl collections than with the bag seines (Fig. 91). At some sampling locations, species richness values were highest in the middle stations (bag seines on TP 2 and GC 2) where salinity ranged from nearly fresh to 11 PSU (Tables 43 and 45). Wagner (1999) showed that freshwater-affiliated fishes clearly react to the position of the tidal freshwater interface, dropping out in salinities above 5 PSU, whereas the tendency of marine fishes to penetrate beyond the oligohaline reach of a given river to be partly dependent upon distance from the main stem of the bay. The species minimum should then be most evident in systems with longest salinity gradients. This salinity gradient was most pronounced in Tres Palacios, and as such, the bag seine collections showed the greatest degree of a species minimum within this system (see Fig. 91a).

In a study of littoral fish assemblages in the tributaries of the lower Chesapeake Bay, Wagner (1999) reported that the incipient stress point associated with salinities lies between 0 – 2 PSU. In this study, the rate of species turnover, or beta diversity, peaked in this salinity range, and marine-affiliated species made larger and more frequent forays across the oligohaline interface than did freshwater-affiliated species. Most of the freshwater species which did penetrate the lower estuary have well-known, if limited, salinity tolerances, and all were most abundant in tidal freshwater (e.g., gizzard shad, bluegill, *Fundulus* sp., see Table 1 in Wagner, 1999). These same species were highly abundant in the middle and lower stations, depending upon the underlying salinity structure during their season of occurrence. It is a common observation that freshwater fishes are generally more constrained by the freshwater interface then their marine counterparts (Moyle and Cech, 1988; Pitcher, 1993). A number of estuarine residents and marine-affiliated species were routinely encountered at the uppermost stations, where freshwater tidal conditions were most common

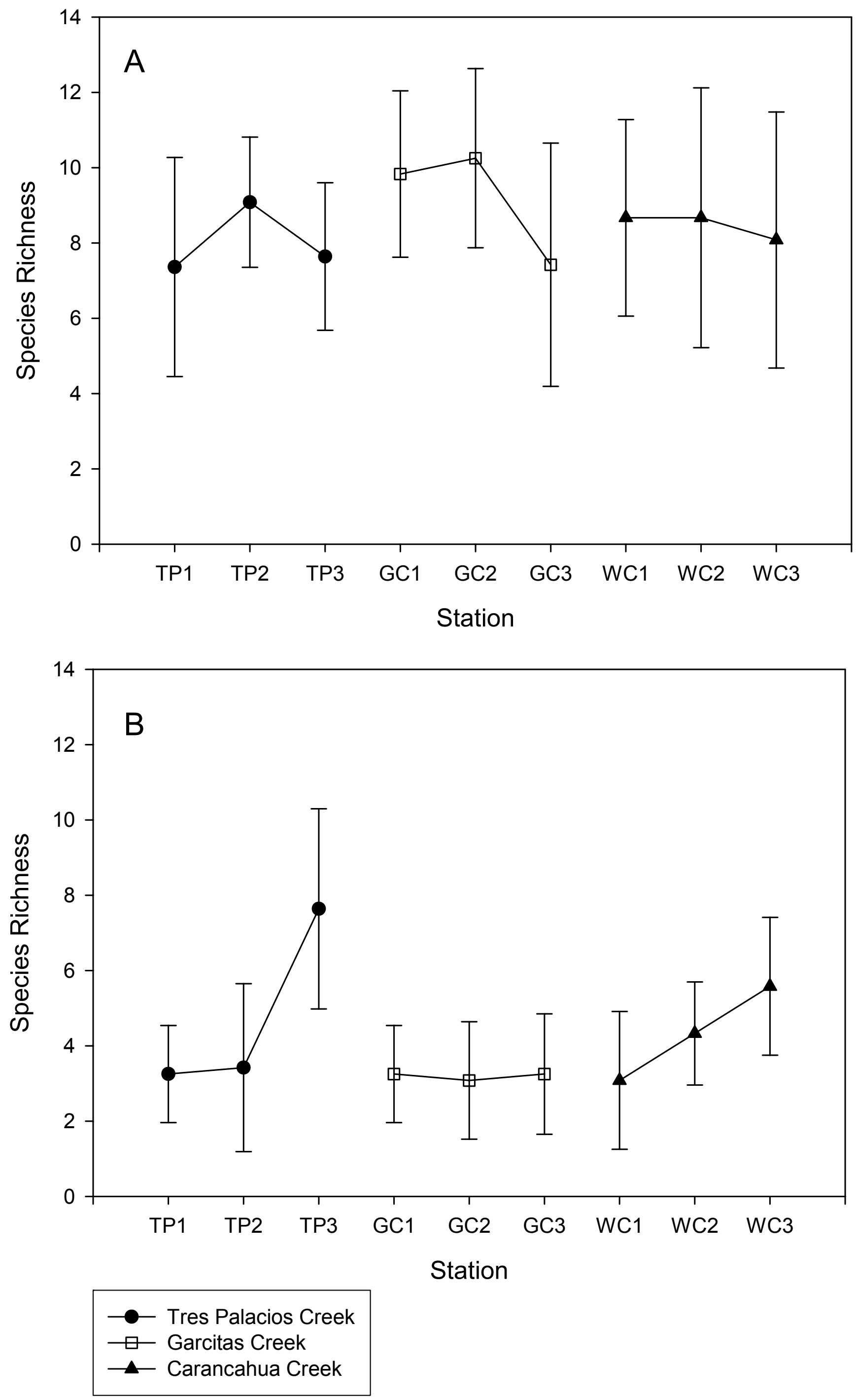


Figure 91. Average species richness (±1 SD) from the fixed sampling locations as measured by A: bag seines, and B: trawls.

(e.g., bull shark, ladyfish, bay anchovy, striped mullet, pinfish, Atlantic croaker, red drum, southern flounder, and hogchokers). These patterns suggest that marine species do not have as sharp a barrier to upstream dispersal as freshwater fish have to downstream dispersal.

An alternate hypothesis for this increase in species richness within the oligohaline waters of the middle stations can be found in the Intermediate Disturbance Hypothesis, an ecological hypothesis which proposes that biodiversity is highest when disturbance is neither too rare nor too frequent (Connell, 1978) With low disturbance, competitive exclusion by the dominant species arises. With high disturbance, only species tolerant of the stress can persist. The notion that disturbance can increase biodiversity opposes the older idea that diversity is highest in undisturbed ecosystems. While this hypothesis has routinely been applied to benthic communities, it can be loosely applied to the nekton communities in this study if one envisions the flooding events as the disturbance mechanism structuring the nektonic community. While it is apparent that euryhaline estuarine fauna show less variation in abundance as salinity changes in mesohaline habitats than do freshwater faunas in tidal freshwater and oligohaline habitats (Peterson and Ross, 1991), the faunal composition of these middle stations appear to be linked to the 'disturbance' of the flooding events.

While hypoxic events, or low dissolved oxygen conditions, occurred frequently in each of the study streams, these conditions did not appear to be a major factor in structuring overall community composition (see Figs. 75b and 75c). The dissolved oxygen regimes within the study streams were heavily influenced by the interaction of temperature, precipitation, nutrient-loading, and salinity stratification, with negative correlations between low dissolved oxygen and elevated bottom water salinities most prevalent on Carancahua Creek (see Fig. 24). While the reference stream showed the greatest spatial extent of hypoxia, there was little to no relationship between dissolved oxygen measurements and species richness (Fig. 92). Equivalent levels of species diversity were noted at high (> 10 mg/L DO), normal (5 mg/L to 10 mg/L DO), as well as low (< 5 mg/L DO) levels. Chronic hypoxia has become a major concern for many estuarine systems (Livingston, 1996; Livingston et al., 1997; Niemi, et al., 2004), with the degradation of nursery habitat and increased potential for harmful effects on important fish stocks listed as some of the effects of hypoxia (Paerl 1997, Howarth et al., 2000; Boesch et al., 2001). Results of studies on the effects of low dissolved oxygen conditions (ranging from 6.0 mg/L down to 0.6 mg/L O_2) showed that direct mortality to both spot (a sciaenid collected from each of the study streams) and Atlantic menhaden (a congeneric equivalent of the Gulf menhaden collected in this study) varied with species, size, and temperature, but was only substantial when those species were exposed to oxygen concentrations less than 1.0 mg/L (McNatt and Rice, 2004; Shimps et al., 2005). These studies point out that dissolved oxygen levels must be severely depressed, and in fact, approaching lethal limits, to negatively impact the population dynamics of these

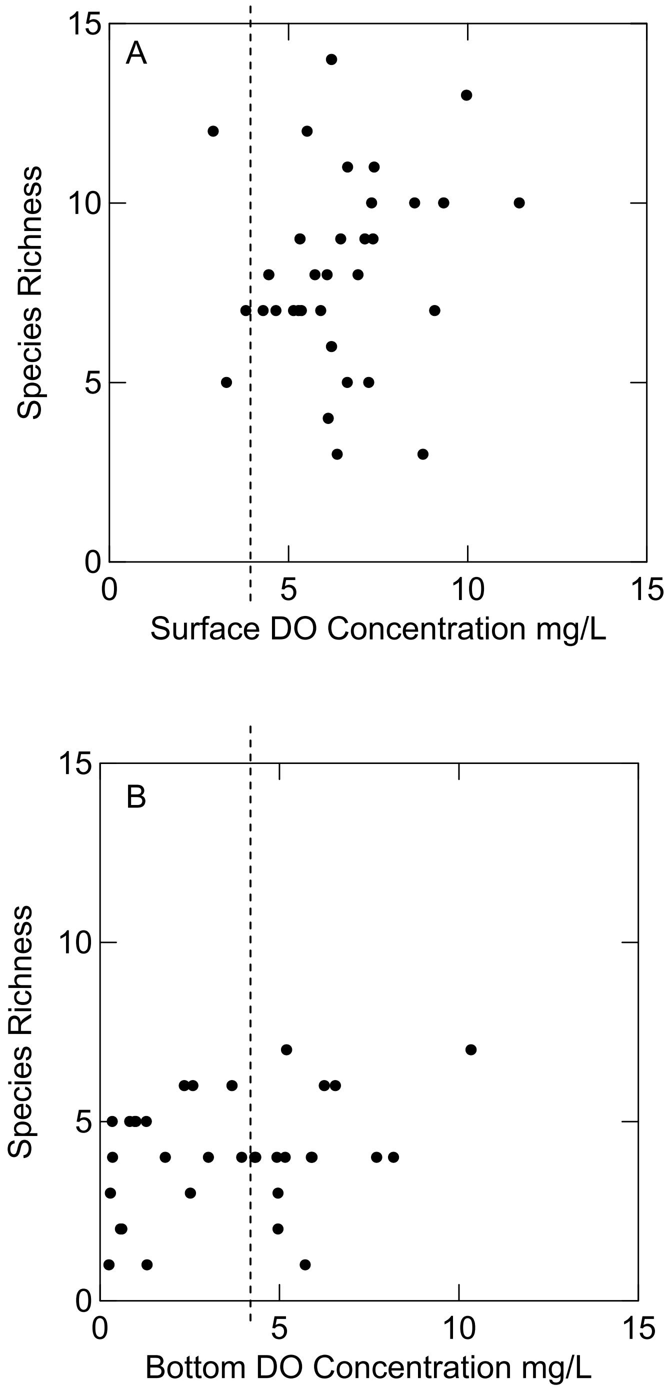


Figure 92. The relationship between (A) species richness (as measured by bag seines) and surface water dissolved oxygen concentrations; and (B) species richness (as measured by trawl collections) and bottom water dissolved oxygen concentrations within Carancahua Creek. Dashed line represents hypoxia conditions (DO ≤ 4 mg/L, as defined by Livingston, 1996).

species. Shimps et al. (2005) points out that the ability of fish to behaviorally avoid hypoxia may limit the mortality directly due to hypoxia. The greatest effects due to hypoxia may be caused by the stress imposed by sublethal hypoxic conditions alone or in concert with other stressors, or by indirect effects incurred by avoiding hypoxia conditions (McNatt and Rice, 2004). While projecting the empirical evidence of a general lack of hypoxia effects of these two estuarine-dependent species onto the myriad of species that comprise the tidal stream communities all along the Texas coast would be a foolhardy endeavor, the results presented in Fig. 92 does reinforce the generality of low dissolved oxygen not appearing to be a strong determining factor in shaping overall community structure found within these tidally influenced habitats.

Benthic Invertebrate Assemblages

Sampling frequency for the benthic invertebrates was only once per season, as opposed to the twice per season frequency for the nekton. This lack of temporal resolution was replaced with a measure of spatial replication, as multiple samples (5 each) were collected from both the middle and the side of the stream at each station. This spatial component was retained in the analysis, as the middle and side collections were treated separately. While far more taxa were recorded from the side collections when compared to the stream middle, the analysis failed to detect any significant differences in overall community assemblages from either within the stations on a common stream, or between each study stream and the reference. Significant seasonality was missing from the benthic collections, although the lack of temporal resolution could have made this a far less powerful test.

The organisms that dominated the benthics in these tidal systems can best be described as ubiquitous. The polychaetes (especially *Streblospio benedicti*), oligochaetes, and chironomids that were common across the salinity gradient-based station design all have wide ranging distributions, although their dominance patterns are often used as indicators of pollution, as many species (particularily *S. benedicti*) are relatively tolerant to high levels of sediment organics (Reish et al., 2005). Often, pollution-tolerant polychaetes remain in areas where more sensitive species have left or died, though heavily polluted areas eventually become completely devoid of life. The flooding events could have negatively affect polychaete distributions through physical burial, removal of suitable habitat via bottom scour, resuspension of silts, or complete displacement downstream. Recolonization by most polychaetes can occur in less than a month, but some studies have indicated that several months to a year may be needed (Martin and Bastida 2006).

Oligochaetes are also used as an indicator of pollution because of their tolerance to organic enrichment. In enriched or oxygen-deficient areas, there are typically high densities of oligochaetes (Lerberg et al., 2000). Diaz (1979) showed that there is an abrupt shift in the community composition of tubificid oligochaetes as one proceeds from tidal freshwater to estuarine habitats. Not only does the species composition change but also their relative trophic importance and their importance to the community. Tidal freshwater forms tend to be larger than estuarine forms and are the major sediment burrowers and bioturbators. The analysis used for this study did not use biomass of the infauna as a comparative measure, but future works could incorporate this variable. Where pollution or other factors result in extreme environmental conditions or reduced habitat diversity, estuarine tubificids tend to become more important, while in tidal freshwater areas these conditions result in little change in community composition (Lerburg et al., 2000). The results of this study are consistent with this finding, as little differences in the upper, middle, or lower stations on any of the tidal streams were markedly different in their community composition. Other opportunistic polychaetes that were common on each of the study study streams included *Polydora* sp., *Laeonereis culveri*, *Capitella capitata*, and *Mediomastus californiensis.* Polychaetes are often one of the first groups to recolonize an area impacted by some disturbance (Lundquist et al., 2004).

The larvae of the chironomids are important as food items for many fish and other aquatic organisms. They are also important as indicator organisms, with the presence or absence of various species in a given body of water giving an indication of what kinds of pollutants may be present and in what quantities (Coffman and Ferrington, 1996). Many of these characteristic benthic infaunal taxa respond to hypoxic conditions by vertically moving to the sediment surface, where they are more vulnerable to predation (Jørgenson, 1980). It is not known if the nekton communities in these tidal streams are specifically feeding on any benthic infauna responding to low DO conditions, but as was the case with the nekton assemblages, the benthic communities do not appear to be greatly structured by dissolved oxygen concentrations. Species richness values for the benthic infaunal communities were nearly uniform across the range of DO conditions encountered, remaining equally diverse even in anoxic conditions (DO concentrations < 1 mg/L, see Fig. 93). The results of the Average Taxonomic Distinctness measure reinforces the evenness of the benthic communities across nearly all the environmental conditions encountered, although this measure did uncover a consistent trend of increased taxonomic diversity in the lower-most stations in each of the study streams (for an example, see Figs. 82a and 88a). This would be consistent with the salinity preferences of a number of polychaetes, with their abundance levels found to be typically higher in mesohaline conditions (Montagna and Kalke, 1992).

Aquatic Invertebrate Assemblages

Compared to the annelids, molluscs and crustaceans, aquatic insects (largely larval forms) make up only a small proportion of the macrofaunal assemblages in

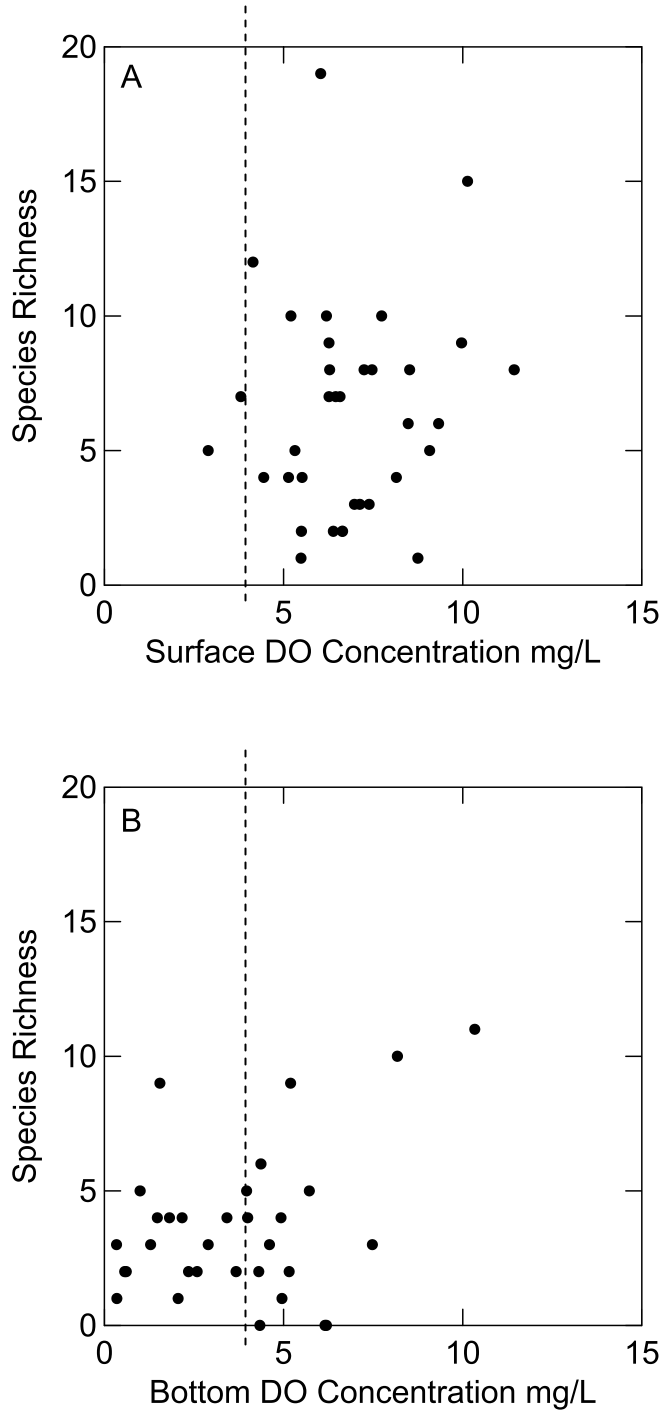


Figure 93. The relationship between (A) benthic invertebrate species richness (stream side collections) and surface water dissolved oxygen concentrations; and (B) benthic invertebrate species richness (stream middle collections) and bottom water dissolved oxygen concentrations within Tres Palacios and Carancahua Creeks. Dashed line represents hypoxia conditions (DO ≤ 4 mg/L, as defined by Livingston, 1996).

coastal marsh habitats. In part, this is attributed to the failure of insects as a group to successfully invade marine environments (Cheng 1976). Those insect groups which are present, however, may at times be numerous and have the potential to play important roles in ecosystem functioning. In addition to serving as potential prey for benthic and epibenthic marsh predators, many of the larval forms of flies (Diptera) are themselves predatory and have the potential to affect populations of other insects as well as other groups within the benthic community (LaSalle and Bishop 1987). In addition, the seasonal emergence of the adult forms may represent a major transfer of carbon from one subsystem (benthic) to another (terrestrial) (Kneib, 1984).

The spatial and temporal patterns of the aquatic invertebrate community structure mirrored that found in the nekton with the bag seines. On Tres Palacios River, the upper and middle stations were significantly different from the lower station (compare Fig. 42 to Fig. 68), and the spring and fall seasons were characterized by significantly different communities. Collections from Garcitas Creek were also remarkably similar to the nekton bag seine collections, as the aquatic invertebrate communities at middle station overlapped with both the upper and the lower stations (compare Fig. 51 and Fig. 71). The inflow-based physical driver for these community differences appears to be operating at many different trophic levels, as insects (Corixidae, Chironomidae, Homoptera, Zygoptera, Lepidoptera, and Empemeroptera) dominated the catch from the upper stations whereas marine crustaceans (Gammaridae, Corophiidae, amd Portunidae) and molluscs (Hydrobiidae) were characteristic of the lower stations. Similar to many of the marine fishes that extended their ranges well up into the freshwater regions of these tidal streams (e.g., striped mullet, southern flounder, and hogchokers), Mysidacea shrimp (a marine crustacean) were far more abundant in the upper stations (see Table 71). Underscoring the variable nature of the aquatic invertebrate collections, no differences in Average Taxonomic Diversity was found within Tres Palacios and the reference stream among stations, or across seasons (Fig. 84 a and b), yet significant differences in these same parameters was seen in comparisons involving Garcitas Creek (the middle and lower stations were more diverse, as well as the spring and summer seasons being more diverse; see Fig. 90 a and b).

RECOMMENDATIONS FOR ASSESSING AQUATIC LIFE USE IN TIDALLY INFLUENCED COASTAL STREAMS

Use attainability analysis (UAA) is intended to provide comprehensive, contemporaneous, high-quality data to be used as a basis for water quality management decisions, including designation and water quality criteria development (Michael and Moore, 1997). Many methods exist for examining biological communities, measuring water chemistry, and investigating physical factors that affect attainment of uses. Because UAA is customized for each application, the development of site-specific methods that result in representative assessment of a water body is justified and may be necessary. This study introduces a new assessment methodology to integrate the physical, chemical, and biological components of ecosystem health in order to determine the appropriateness of the designated uses.

Specific uses are evaluated on the basis of a criteria, or a standard, which is a numerical or narrative statement established by an authority upon which judgment can be based. To date, the many unclassified tidally-influenced coastal streams within the State of Texas have been presumed to have a high aquatic life use and the corresponding dissolved oxygen criteria (minimum average of 4.0 mg/L DO over a 24 hour period, and a daily minimum of 3.0 mg/L DO, see Table 1) has been used to evaluate their attainment (TCEQ 2000a). Tres Palacios Tidal (Segment 1501) currently has an aquatic life use classification of "exceptional", and the DO criteria for this classification is somewhat higher (5.0 mg/L 24 – hour minimum average and 4.0 mg/L daily minimum). Due to the fact that routine monitoring has uncovered depressed dissolved oxygen levels on the tidal portions of both Tres Palacios River and Garcitas Creek, these segments are currently considered impaired (Draft Texas 303(d) List 2004).

Biological evaluation criteria provides information on the community composition, overall health, and abundance of the various trophic levels of biota residing in a water body, as well as the physical habitat in which they live. This is accomplished by a comparison of the resident biota in the test water body (Tres Palacios and Garcitas Creek) with a similar reference water body which has been impacted only to a minimal extent by humans. As there are likely few places along the Texas coast unaffected by anthropogenic disturbances, true reference areas remain elusive. For this study, the reference stream (Carancahua Creek) was chosen such that it represented the best attainable environmental conditions within the same geographic setting. The primary task of this study was to determine whether any differences in the physical, chemical, or biological components of the ecosystem could be found between the reference stream and each of the study streams.

The choice of a reference stream is therefore critical in the context of evaluating designated uses. Using the conceptual framework laid out in Fig. 10 as the starting point for comparisons of ecological conditions, little differences in either the physical, chemical, or biological structure was found between the reference stream and either of the study streams. The greatest degree of difference in indicators of ecosystem health all involved upstream – downstream gradients that appear to be significantly correlated with salinity structure (the upper and middle stations were similar and significantly different from the lower station). These salinity-driven gradient conditions cut across all of the levels of ecological integrity that were measured for this study. For example, the means plot MDS ordination of surface water quality (Fig. 16) matches quite well the biological-based configuration of bag seine collections (Fig. 42), and this same pattern is repeated with the aquatic invertebrate collections (Fig. 68). What is not seen is a clear separation of the reference stream from the “impaired or impacted” stream at any level of ecosystem health. Conceptually, if the impacted streams were clearly different from the reference condition, then the multivariate ordination techniques proposed in this study should graphically illustrate these differences (Fig. 94). In this hypothetical example, the reference stream (Exceptional Aquatic Life Use designation, Stream A) has a clearly different biological constituent than the “impacted” locations (Intermediate Aquatic Life Use designated Streams F and G). A gradient of biological conditions encompassing a variety of High Aquatic Life Use is represented by streams B, C, E, and H (Fig. 94). This overlap of biological conditions within the High Use group could clearly represent the results of this study: Carancahua Creek is inherently similar to both Tres Palacios and Garcitas Creek in terms of the physical, chemical, and biological parameters measured for this study. With only two streams to portray within each ordination, differences between the reference condition and the study stream must be very large to show any clear separation.

Should the occurrence of depressed dissolved oxygen conditions in tidally influenced habitats automatically lead to a lowering of the Aquatic Life Use category? Based on the results of this study, dissolved oxygen concentration does not appear to be one of the major structuring factors in the physical, chemical, or biological components of ecosystem health. The attributes currently used to assess ‘use’ (habitat characteristics, diversity, species richness, and trophic structure) were generally equal, if not higher, within the impacted streams of Tres Palacios and Garcitas Creek. The final attribute in assessing ‘use’ is the abundance of “sensitive species”. Given the extreme euryhaline / physiological abilities of many of the species that comprise the biological communities found within tidal systems, few estuarine taxa can truly be described as “sensitive”. The susceptibility of individual organisms to hypoxia is generally determined by a combination of physiological tolerances and their behavioral responses. In spite of the negative effects of low dissolved oxygen, some estuaries with widespread seasonal hypoxia are among the most productive systems for fisheries worldwide. In other cases, oxygen depletion has been associated with massive and repeated fish kills, extensive mortality of benthic organisms, and reduced recruitment of important species. Overall, the biological sensitivity of estuarine systems depends on how these physiological sensitivities and potential responses of organisms interact with the physical features of within the estuary which control the temporal and spatial distribution, duration, and extent of these conditions.

The strength of the community approach lies in the differential sensitivity of individual species, functional groups, or trophic levels to different levels of stress, and the ability to sample a wide variety of taxa; each with a unique life history capable of being disrupted by these stressors at various scales. Returning to the Methodology proposed in Fig. 10, once a significant difference in the multivariate

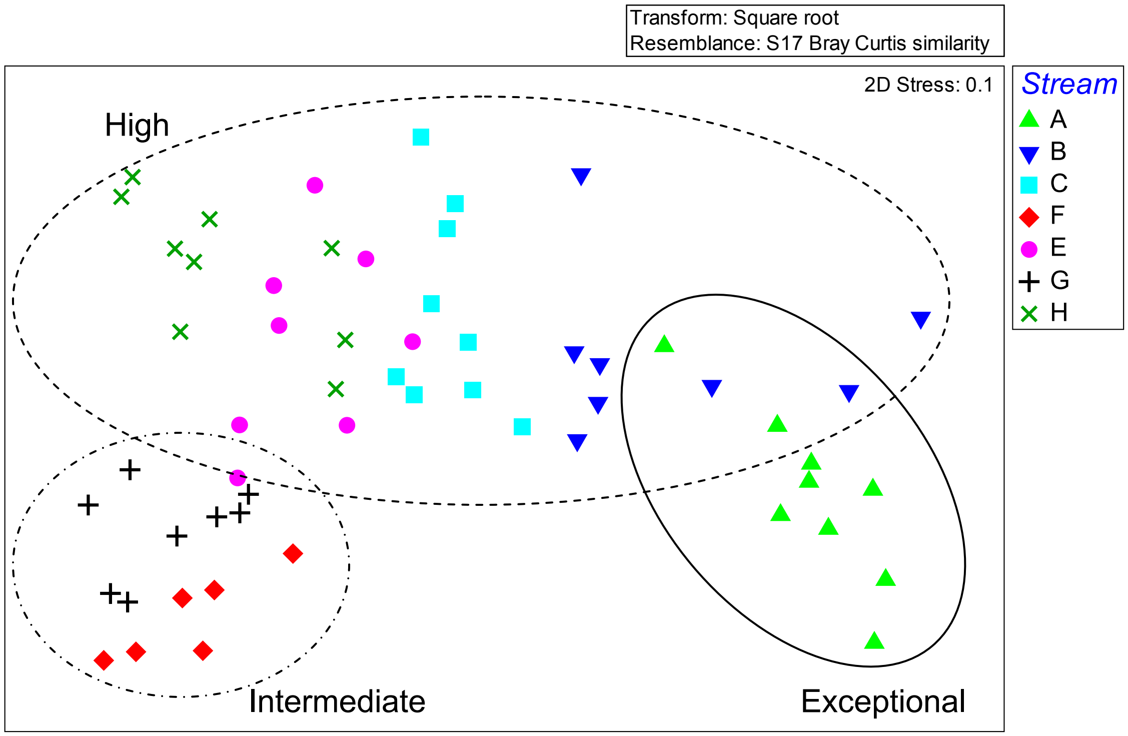


Figure 94. Hypothetical MDS ordination of biological collections from seven tidally influenced coastal stream. Stream A is designated as the Reference Stream. Aquatic Life Use designations as follows: Stream A = Exceptional (enclosed in solid line ellipse); Streams B, C, E, and H = High (enclosed in dashed line ellipse); and Streams F and G = Intermediate (enclosed in dash-dotted line ellipse).

structure of ecosystem health can be established between a study stream and the reference condition, analytical techniques allow for the determination of which constituent(s) are sensitive to the underlying differences (SIMPER analysis, BEST analysis, and Average Taxonomic Diversity tests). This is graphically represented in Fig. 10 Part C (Index Development), where “sensitivity of indicator taxa to changes in other chemical and physical data collected” can be used to compute Index Scores. These techniques applied to the salinity-mediated differences found in this study were equivocal, as the physical, chemical, and biological character of the study streams were very similar to the reference stream. As such, no Biocriteria for Tidal Streams could be developed that would have applicability over large spatial scales.

Are the current Aquatic Life Use designations appropriate for each of the streams under investigation?

Tres Palacios Tidal (Segment 1501) – Exceptional, Impacted for Low DO

Garcitas Creek Tidal (Segment 2453A) – Presumed High, Impacted for Low DO

Carancahua Creek (Segment 2456) – Presumed High

Based on the results of this study, no clear difference was found between the Exceptional and the High classifications. Whether the Exceptional designation of Tres Palacios is too high or the High designations of Garcitas Creek and Carancahua Creek are too low will ultimately depend upon the incorporation of additional datasets into a coast-wide MDS ordination, as suggested by Fig. 94.

If the analytical approach outlined in this report is to be utilized in determining appropriate Aquatic Life Use designations in other tidally influenced systems, recommendations on the spatio-temporal scales of sampling effort are needed in order to incorporate these new datasets. The authors therefore make these specific recommendations:

Physical Properties Sampling – Continue collection of Field Parameter profiles, but eliminate the mid-depth measurements. In situations where vertical stratification of the water column was evident, the surface and bottom samples were sufficient to capture this condition. The mid-depth collection was typically redundant, in that conditions in the middle of the water column were generally similar to both the surface and the bottom measurements. The true differences were found in the surface and bottom collections, and these collections could be directly linked to the chemical (surface and bottom measurements) and the biological (bag seines, trawls, and gill nets) sampling efforts.

Continue collection of the Short-Term 24-hour Datasonde Deployments, but ensure each instrument is equipped with the same suite of probes. Given the multivariate tests utilized in the analysis Methodology, missing data (e.g., pH probes not functioning) leads to the elimination of all other parameters collected with that deployment.

Landcover Classification - Further study would be useful in determining the actual amount of development within the live oak landcover class. It might also be helpful to assess the percent of full time residents in these communities and the amounts and types of additional nutrients and chemicals coming from this land use would be beneficial. Also, information about the addition of possibly more nutrients into the system from the grassland class as opposed to the shrub classes may also be needed.

Instream flow - The results of this study provide a quantitative assessment of the influence of tidal cycles on flows within coastal streams and rivers. However, additional studies are needed to determine an appropriate methodology for collecting and analyzing flow data in tidally influenced streams. Such a methodology will help to standardize measurements, thus reducing variation and improving estimates of tidal influence. From this point, it then will be possible to better assess the impacts of tidal cycles on aquatic life use of coastal streams, particularly in relation to seasonal variation in instream flow.

Chemical Properties Sampling – Continue collection of Bottom Water Quality parameters, but eliminate the surface collections as these were generally redundant, even during stratified conditions. During conditions of high flow, the entire water column was well mixed. The only Biological collections to be significantly related to the multivariate structure of the Water Quality collections were the trawl samples, and these were related to bottom water quality conditions.

Continue collection of Sediment parameters, but eliminate the side collections as these were generally redundant and closely related to the middle collections. Increase the frequency of sediment collections to match the temporal resolution of the biological collections (twice per season).

Biological Properties Sampling – Continue collection of the nekton assemblages, but eliminate the gill net collections. This gear collected a far different community than either the bag seines or the trawls, and a large majority of the estuarine taxa that characterized the tidal streams under investigation were completely missing from this gear. Additionally, this gear failed to detect any of the spatial or temporal differences in the nekton communities that were quite evident with the other nekton gears. Other shortcomings with this gear included a number of samples compromised by alligator attacks, as well as a number of net deployments completely missing (presumably as the result of human intervention; i.e., nets stolen overnight). Flooding, as well as higher flow conditions, within these systems was an important determinant on the biological community structure measured, and the gill nets were not able to sample during these periods.

Continue collection of benthic infauna, but eliminate the side collections as these were generally redundant and closely matched the community structure of middle collections. Increase the temporal resolution of the benthic infauna to match the frequency of the nekton collections.

Eliminate the aquatic invertebrate collections, as these collections were temporally and spatially the most variable in terms of their overall community structure; were not significantly related to the multivariate structure of the water column profiles or the water quality parameters; and were far and away the most man-power intensive samples to process.

Spatio-Temporal Scales of Sampling Effort - Eliminate the middle station collections from future efforts, as the upper and middle stations were generally similar in all components of ecosystem health measurements. The upper and lower stations are generally sufficient to characterize ecological conditions on a tidal stream.

While seasonality was quite evident in each study stream, the level of effort to obtain this seasonally replicated data was quite high. If future comprehensive assessments of condition are either cost prohibitive or limited by man-power considerations, future collections should concentrate on a temporal scale capable of detecting and diagnosing those environmental conditions. Based on the results of this study, collections should be concentrated during either the spring or the fall, as consistent patterns of ecological health were found in these seasons. This is a departure from the current “summer index period” currently used to assess biological and ecological conditions. In each stream investigated for this study, the summer period was the most variable and generally lacked any consistent patterns between the physical, chemical, and biological components of ecosystem health.

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Appendix 1. Table of nekton data from Bowman (1991).

Table 16.–Nekton (Garcitas Creek Tidal)

Species	Common Name	Nov 88	Mar 89	May 89	Aug 89
Anchoa mitchilli	(Bay Anchovy)	0	2	0	0
Brevoortia patronus	(Gulf Menhaden)	0	2	129	328
Callinectes sapidus	(Blue Crab)	0	0	0	0
Cyprinodon variegatus	(Sheepshead Minnow)	1	0	0	0
Dorosoma petenense	(Threadfin Shad)	0	0	0	0
Etheostoma chlorosomum	(Bluntnose Darter)	0	0	0	0
Eucinostomus gula	(Silver Jenny)	0	0	0	1
Fundulus chrysotus	(Golden Topminnow)	0	0	0	0
Fundulus grandis	(Gulf Killifish)	3	1	0	9
Fundulus pulvereus	(Bayou Killifish)	2	0	0	0
Gambusia affinis	(Mosquito Fish)	1	0	0	0
Ictalurus punctatus	(Channel Catfish)	0	0	0	0
Ictiobus bubalus	(Smallmouth Buffalofish)	0	0	0	0
Lagodon rhomboides	(Pinfish)	0	0	1	0
Lepomis macrochirus	(Bluegill)	0	0	0	0
Lepomis marginatus	(Dollar Sunfish)	0	0	0	0
Lepomis punctatus	(Spotted Sunfish)	0	0	0	0
Lepomis sp.	(Hybrid Sunfish)	0	0	0	0
Membras martinica	(Rough Silverside)	3	0	0	0
Micropogon undulatus	(Atlantic Croaker)	0	0	1	0
Micropterus punctulatus	(Spotted Bass)	0	0	0	0
Micropterus salmoides	(Largemouth Bass)	0	0	0	0
Mugil cephalus	(Striped Mullet)	0	0	2	1
Notropis amabilis	(Texas Shiner)	0	0	0	0
Notropis venustus	(Spottail Shiner)	0	0	0	0
Palaemonetes kadiakensis	(Freshwater Shrimp)	0	2	0	0
Penaeus aztecus	(Brown Shrimp)	0	0	4	0
Penaeus duorarum	(Pink Shrimp)	2	0	0	0
Penaeus setiferus	(White Shrimp)	44	0	0	3
Sciaenops ocellata	(Red Drum)	0	2	0	0
All Species		56	9	137	342
Mean no. species/cast		0.7	0.5	0.5	0.5
Mean no. individuals/cast		5.6	0.9	13.7	34.2
Mean biomass/cast (g)		5.74	0.62	103.63	73.9
Total no. species		7	5	5	5
Total no. individuals		56	9	137	342
Total biomass (g)		57.4	6.2	1036.3	739.8
Density (no. individuals/sq. m)					
Shannon-Weiner diversity		0.89	1.58	0.29	0.31
Evenness		0.46	0.98	0.18	0.19

Appendix 2. Data table from Linam et al 2002.

Fish species collected from West Carancahua Creek, Jackson County (9/7/88).

Species	Common Name	Seine (7 hauls)	Backpack Shocker (10.3 min)
Anguilla rostrata	American eel		1
Cyprinella lutrensis	Red shiner	1360	3
Opsopoeodus emiliae	Pugnose minnow	9	1
Pimephales vigilax	Bullhead minnow		1
Ameiurus natalis	Yellow bullhead		1
Ictalurus punctatus	Channel catfish	32	16
Noturus gyrinus	Tadpole madtom	1	
Gambusia affinis	Western mosquitofish	430	2
Lepomis cyanellus	Green sunfish	3	9
Lepomis gulosus	Warmouth		5
Lepomis macrochirus	Bluegill		2
Lepomis megalotis	Longear sunfish		1

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Appendix 3. Table from Bayer et al, 1992

TEXAS WATER COMMISSION ECOREGION INVERTEBRATE DATA

STATION 2400.0330
West Caranchua Creek - Jackson Co.
@ Jackson County Rd. 440 (Bonnot Rd.) 5.6 km NE Laward
DATE 09/07/88
ECOREGION 34
SAMPLES 3 sq. ft. Surbers

Code	Genus/species	No.	No./M^2	No./ft^2
90045	*Hydra* sp.	1	4	0.33
90077	*Dugesia tigrina*	1	4	0.33
90501	*Aulodrilus pigueti*	2	7	0.67
90507	*Limnodrilus hoffmeisteri*	11	39	3.67
90510	*Limnodrilus udekemianus*	11	39	3.67
92875	*Physella virgata*	1	4	0.33
93031	*Pisidium casertanum*	29	104	9.67
93040	*Sphaerium transversum*	153	549	51
91101	*Eucypris* sp.	2	7	0.67
92230	*Dubiraphia* sp.	1	4	0.33
92242	*Microcylloepus pusillus*	2	7	0.67
92259	*Stenelmis occidentalis*	290	1041	96.67
92645	*Cladotanytarsus* sp. gr. A	17	61	5.67
92502	*Conchapelopia* sp.	56	201	18.67
90999	*Cricotopus trifascia* gr.	26	93	8.67
92523	*Cryptochironomus fulvus* gr.	13	47	4.33
93294	*Polypedilum convictum*	77	276	25.67
93289	*Polypedilum illinoense*	4	14	1.33
92635	*Polypedilum* nr. *scalaenum* sp. B	17	61	5.67
92538	*Pseudochironomus* sp.	94	337	31.33
92469	*Saetheria* sp.	4	14	1.33
92423	*Tanytarsus glabrescens* gr.	39	140	13
92554	*Tanytarsus* sp.	4	14	1.33
92588	*Thienemanniella* sp.	13	47	4.33
91663	*Baetis ephippiatus*	1	4	0.33
91600	*Caenis* sp.	149	535	49.67
91651	*Fallceon quilleri*	17	61	5.67
91656	*Paracloeodes* sp.	2	7	0.67
91595	*Tricorythodes albilineatus* gr.	255	915	85
91713	*Erpetogomphus* sp.	3	11	1
91732	*Progomphus obscurus*	3	11	1
92292	*Cheumatopsyche* sp.	59	212	19.67
92324	*Hydroptila* sp.	18	65	6
92399	*Oecetis* sp. B	1	4	0.33

Appendix 4. Analysis of stream flow data in tidal streams of the Texas coast. This report has been edited to only include the mid-coast sampling stations. For entire report see TWDB 2006.

Appendix 5. Synopsis of weather data obtained from National Climatic Data Center at Tres Palacios airport.

Date	Wind Direction	Wind Speed (knots)	Time	Temperature (ºF)	Precipitation (inches)
April 2003					
6 Apr 2003	S SE	10 - 15	00:00 - 23:00	71	none
7 Apr 2003	S SW	8	00:00 - 07:00	71	none
7 Apr 2003	E	7	07:00 - 15:00	71	none
7 Apr 2003	SE	8	16:00 - 19:00	72	none
8 Apr 2003	E NE	10	00:00 - 04:00	69	none
8 - 10 Apr 2003	N	13 - 20 gusts to 37	05:00 - 02:00	44 - 68	trace
10 Apr 2003	calm	calm	02:00 - 07:00	45 - 56	none
10 Apr 2003	S SW	8	07:00 - 00:00	67	none
May 2003					
4 - 8 May 2003	SE SW	10 - 22 gusts to 30	Entire sampling event	76 at night 84 day	none
June 2003					
22 - 26 June 2003	SW SE	10 - 18	Entire sampling event	83 at night 91 day	none to trace
August 2003					
3 - 7 Aug 2003	SW SE	9 - 14	Entire sampling event	83 at night 91 day	none
September 2003					
21 - 23 Sept 2003	ENE to N	5 - 14	01:00- 18:00	68 - 86	4 - 6
23 - 25 Sept 2003	E - SE	3 - 10	19:00 - 23:00	68 - 86	none
November 2003					
2 - 6 Nov 2003	ESE - S	5 - 15 lay at night and harder during day	Entire sampling event	66 - 83	none to trace
March 2004					
21 Mar 2004	SE	6 - 10	00:00 - 07:00	65 - 70	none
21 Mar 2004	calm	calm	08:00 - 11:00	64	none
21 Mar 2004	N NE	5 - 10	12:00 - 16:00	64 - 70	none
21 - 22 Mar 2004	E	5 - 15	17:00 - 05:00	65 - 82	none
22 Mar 2004	N	0 - 5	06:00 - 12:00	57 - 63	none
22 - 26 Mar 2004	E - SE	5 - 20	Rest sampling event	63 - 75	none
May 2004					
9 - 11 May 2004	SE	9 - 21	00:00 - 19:00	66 - 74	trace to 1 on the 9th

Appendix 5 (Cont.)

Date	Wind Direction	Wind Speed (knots)	Time	Temperature (ºF)	Precipitation (inches)
11 May 2004	NE	0 - 10	20:00 - 00:30	68 - 72	5 - 6
12 May 2004	SE	14 - 21 gusts to 25	02:00 - 21:00	75 - 84	trace
13 May 2004	NE	18 - 36	22:00 - 23:00	66 - 75	1
July 2004					
5 - 8 July 2004	SE - SW	8 - 15	Entire sampling event	81 - 90	none
August 2004					
2 Aug 2004	SE	0 - 13	00:00 - 06:00	82 - 86	none
2 Aug 2004	N NE	6	07:00 - 16:00	77 - 89	none
2 - 3 Aug 2004	S SE	0 - 13	19:00 - 08:00	81 - 90	trace
3 Aug 2004	NE	3 - 8	09:00 - 16:00	78 - 91	none
3 - 4 Aug 2004	S	9 - 13	20:00 - 07:00	84 - 91	none
4 Aug 2004	NW	0 - 6	08:00 - 17:00	77 - 90	none
4 - 5 Aug 2004	S	7 - 14	18:00 - 09:00	84 - 91	none
5 Aug 2004	W	0 - 5	10:00 - 17:00	78 - 91	none
5 Aug 2004	S	9 - 12	18:00 - 23:00	91 - 94	none
September 2004					
19 Sept 2004	SE	6 - 8	00:00 - 10:00	75 - 77	none
19 Sept 2004	NE	7	11:00 - 14:00	74 - 80	none
19 - 20 Sept 2004	SE	5 - 15	15:00 - 06:00	70 - 74	none
20 Sept 2004	NE E	7	08:00 - 15:00	72 - 84	none
20 Sept 2004	SE	9 - 18	16:00 - 00:00	80 - 89	none
21 Sept 2004	NE	5 - 8	03:00 - 13:00	69 - 74	none
21 Sept 2004	E SE	12 - 21 gusts to 31	14:00 - 23:00	75 - 84	trace
22 Sept 2004	NE E	0 - 10	01:00 - 14:00	70 - 78	none
22 Sept 2004	E SE	13 - 20 gusts to 29	15:00 - 23:00	81 - 87	none
23 Sept 2004	E	9	00:00 - 04:00	72 - 74	none
23 Sept 2004	N NE	7	05:00 - 18:00	70 - 88	trace
23 Sept 2004	SE	10	19:00 - 23:00	83 - 87	none
November 2004					
7 Nov 2004	S SW	6	01:00 - 09:00	60 -74	none
7 Nov 2004	NW	5	10:00 - 19:00	54 - 76	none
7 - 8 Nov 2004	S	7	20:00 - 05:00	65 - 77	none
8 Nov 2004	NE	6	07:00 - 18:00	57 - 78	none
8 - 9 Nov 2004	SE	7	19:00 - 01:00	68 - 80	none
9 Nov 2004	NE E	3 - 12	02:00 - 17:00	57 - 75	none
9 - 10 Nov 2004	E	5 - 14	18:00 - 09:00	63 - 78	none
10 - 11 Nov 2004	S	3 - 17 gusts to 21	10:00 - 12:00	68 - 80	none
11 Nov 2004	NW	3 - 21 gusts to 26	12:00 - 23:00	64 - 74	none

Appendix 6. Taxonomic list and total numbers of fish collected, by gear, from Garcitas Creek, Tres Palacios River, and Carancahua Creek. List arranged by taxa rank as measured by total number of individuals collected.

	Garcitas Creek			Tres Palacios River			Carancahua Creek		
Taxa	Gill Net	Trawl	Bag Seine	Gill Net	Trawl	Bag Seine	Gill Net	Trawl	Bag Seine
Gulf menhaden	57	8793	32161	55	15799	2606	18	19656	32990
Bay anchovy		14893	4519		15523	1591		18907	4506
Atlantic croaker	6	508	91	1	1533	401	2	1269	131
Blue catfish	368	32	61	102	330	76	79	285	91
Western mosquitofish			265			432		2	366
Spot	4	15	271	5	36	244	1	42	194
Sailfin molly			611			36			49
Striped mullet	13	5	228	27	7	98	30	2	247
Sand seatrout	1	5	6	7	317	61		149	50
Gizzard shad	89	4	115	129	4	7	143	2	3
Hardhead catfish	91	2		178	12	1	90	4	
Spotted gar	94	2	2	69	5	2	175	8	2
Red drum	73	7	5	55	15	9	87	3	7
Smallmouth buffalo	72			78		1	103	1	1
Tidewater silverside			86			61			102
Hogchoker		1	18		43	71		6	47
Silver perch	23	2	2	13	12	13		37	43
Bay whiff			77		5	5		1	11
Pinfish			62	1		11		1	23
Mojarra sp.			57			13		1	18
Gafftopsail catfish	38	1		28	6		3		
Longnose gar	19	1	1	38		2	9	2	
Ladyfish	9	1	10	10		8	4	4	19
Naked goby			20		2	24		3	11
Southern flounder	3		13	1	4	26			11
Gulf killifish			49						5

Appendix 6 (Cont.)	Garcitas Creek			Tres Palacios River			Carancahua Creek		
Taxa	Gill Net	Trawl	Bag Seine	Gill Net	Trawl	Bag Seine	Gill Net	Trawl	Bag Seine
Lepomis sp.		1	17			1		1	28
Saltmarsh topminnow			44			1			3
Black drum	12			16	1	1	6	10	
Spotted seatrout	14		6	7	7	9	1	1	
Scaled sardine	30			8			1		
Bluegill			2			1		3	22
Golden topminnow			17			3			5
Sheepshead minnow			22						3
Rainwater killifish						13			8
White crappie	12		1			1	2		3
Largemouth bass	7		8						1
Bull shark	3			5			4		
Atlantic leatherjacket			9			2			
Channel catfish				3		2	3		3
Silverside									11
Least puffer			1		5	4			
Blackcheek tonguefish					8	1			
Sheepshead	2			5			2		
Warmouth					1	1			6
Diamond killifish			6						1
Flathead catfish	2			3			2		
Gulf pipefish			3			1			3
Longnose killifish			7						
Threadfin shad	1	2		2	1		1		
Black crappie	3		3						
Bluntnose jack		1						1	4
Common carp	1			3			2		
Alligator gar	2			2		1			
Sharptail goby					1				4
Bayou killifish			4						

Appendix 6 (Cont.)	Garcitas Creek			Tres Palacios River			Carancahua Creek		
Taxa	Gill Net	Trawl	Bag Seine	Gill Net	Trawl	Bag Seine	Gill Net	Trawl	Bag Seine
Darter goby			4						
Family Ictaluridae			3		1				
Family Lepisosteidae			1	1		1			1
Finescale menhaden				1	2		1		
Freshwater drum				2			2		
Green goby		1				3			
Atlantic needlefish						1			2
Red shiner						3			
Atlantic thread herring		1						1	
Bullhead minnow						2			
Chain pipefish			1			1			
Code goby					2				
Common snook	1						1		
Family Fundulidae			1		1				
Fat sleeper			2						
Freshwater goby					1			1	
Green sunfish			1						1
Atlantic midshipman					1				
Bighead searobin					1				
Eel					1				
Family Clupeidae			1						
Family Gobiidae						1			
Family Syngnathidae			1						
Inland silverside						1			
Lined sole			1						
Mimic shiner						1			
Redear sunfish							1		
Southern stingray							1		
Violet goby					1				
White bass	1								
Yellow bullhead				1					

Appendix 7. Taxonomic list and total numbers of invertebrates and other taxa collected, by gear, from Garcitas Creek, Tres Palacios River, and Carancahua Creek. List arranged by taxa rank as measured by total number of individuals collected.

	Garcitas Creek			Tres Palacios River			Carancahua Creek		
Taxa	Gill Net	Trawl	Bag Seine	Gill Net	Trawl	Bag Seine	Gill Net	Trawl	Bag Seine
White shrimp	1	25	1281		1608	2324		292	1425
Brown shrimp		23	399		393	1528		27	608
Grass shrimp		12	813		17	780		11	1083
Blue crab	3	34	135	12	71	96	2	22	139
Family Macrobrachium		1	5		43	188		15	56
Pink shrimp		1	3		3	105		3	3
Family Unionidae			27		12	25			45
Rangia clam						23			4
Family Xanthidae			5		1	8			3
Crawfish						4		1	4
Family Penaeidae		4			5				
Other Taxa									
Tadpole		2	18			4		2	3
Red ear slider turtle					1				

Appendix 8. Taxonomic list and total numbers of benthic macroinvertebrates collected from the middle and side collections from Garcitas Creek, Tres Palacios River, and Carancahua Creek. List arranged by taxa rank as measured by total number of individuals collected.

	Garcitas Creek		Tres Palacios		Carancahua Creek	
Taxa name	middle	side	middle	side	middle	side
Chironomidae	165	109	45	229	53	303
Oligochaeta	95	173	38	232	70	277
Corophium louisianum		15		178	1	653
Streblospio benedicti	294	11	107	55	38	27
Polydora	8		1	410	2	59
Amphicteis floridus	15	48	7	158	3	63
Laeonereis culveri		175	3	3		11
Polydora ligni		3		169		2
Odostomia laevigata	6	5	5	113	7	4
Hydrobiidae	3	2	16	32	43	13
Rangia	18	30	6	23	4	23
Nemertea	36	17	3	20	4	19
Baetidae	1	1		63		
Mediomastus californiensis	36	1	13	2	1	
Capitella capitata	3	3	7	24	1	
Edotia sublittoralis				32		
Gastropoda			3	16	9	4
Texadina barretti		3	2	8	4	13
Parandalia	2	15	3	3		
Corixidae		12		1		7
Capitellidae		8	7			
Edotia montosa				14	1	
Nemata		1	2	8	1	1
Polydora socialis						11
Araneae	1		4	2	1	2
Macoma mitchelli		10				
Culicidae			1		4	3
Rangia cuneata				5	1	2
Macoma	1	6				
Mytilopsis leucophaeata	1	1		4		
Ceratopogonidae	1	1		2		1
Gammarus mucronatus				5		
Mysidacea		1		2	2	
Zygoptera						5
Anomalocardia auberiana	1				3	
Bezzia				3		1
Dyspanopeus texanus				4		
Neanthes succinea				4		
Trepobates becki			1	3		
Brachidontes exustus				3		
Caenidae						3

Appendix 8 (cont.)	Garcitas Creek		Tres Palacios		Carancahua Creek	
Taxa Name	middle	side	middle	side	middle	side
Eteone heteropoda				3		
Exogone dispar			2	1		
Homoptera				3		
Portunidae			1	1		1
Callinectes sapidus				2		
Chaoboridae			2			
Ericthonius brasiliensis		2				
Gerridae	2					
Nepidae						2
Oedicerotidae		2				
Probythinella					2	
Rheumatobates				2		
Sphaeromatidae			1	1		
Spiophanes				2		
Aricidea fragilis				1		
Caenis				1		
Carabidae					1	
Collembola				1		
Ephemeroptera				1		
Glycera americana			1			
Gyrinidae						1
Hemiptera				1		
Heptageniidae	1					
Hyalella azteca				1		
Hydrophilidae						1
Macoma tageliformis					1	
Odonata		1				
Odostomia					1	
Prionospio heterobranchia		1				
Rhithrogena				1		
Sciomyzidae		1				
Siphonoecetes smithianus		1				
Spiophanes bombyx						1
Stratiomyidae				1		
Tellina				1		
Trichoptera				1		
Turbellaria						1
Turbonilla portoricana						1

Appendix 9. Taxonomic list (family-level identification) and total numbers of aquatic invertebrates collected with D-frame nets from Garcitas Creek, Tres Palacios River, and Carancahua Creek. List arranged by family rank as measured by total number of individuals collected.

Family	Garcitas Creek	Tres Palacios	Carancahua Creek
Mysidacea	8569	1016	19832
Chironomidae	1215	2635	2566
Corixidae	3256	1830	768
Hydrobiidae	1353	991	637
Gammaridae	364	1855	293
Gerridae	738	327	784
Araneae	444	181	416
Oniscidea	916		1
Oligochaeta	116	351	347
Homoptera	367	48	165
Corophiidae	87	432	37
Portunidae	148	289	48
Ampharetidae	10	340	87
Baetidae	69	30	240
Taltridae	142	17	98
Physidae	5	74	161
Zygoptera	45	28	140
Hydrophilidae	90	17	101
Planorbidae	155	6	37
Lepidoptera	24	16	115
Spionidae	21	82	13
Ephemeroptera	44	21	45
Dreissenidae	83	12	10
Ceratopogonidae	24	31	45
Taltroidea		16	66
Assimineidae	5		72
Hyalellidae	23	8	46
Haliplidae	25	17	32
Sphaeromatidae	41	10	20
Coenagrionidae	6	10	53
Saldidae	40	5	21
Diptera	4	42	19
Lymnaeidae	24	7	34
Nepidae	45		17
Dysticidae	12	18	23
Culicidae	12	14	24
Caenidae	5	12	32
Elmidae	22	7	14
Mactridae	4	22	14
Orthoptera	30	3	7
Diplopoda	29		10

Appendix 9 (cont.)

Family	Garcitas Creek	Tres Palacios	Carancahua Creek
Scirtidae	30	1	8
Polygyridae		11	23
Belostomatidae	16	6	11
Ancylidae		23	8
Curculionidae	4	16	11
Stratiomyidae	20	3	8
Nereididae	21	8	
Tricorythidae	26		
Anisoptera		3	20
Libellulidae	8	4	11
Belastomatidae	2	7	12
Xanthidae	1	20	
Dolichopodidae	16	2	2
Coleoptera	13	2	4
Odonata		7	12
Trichoptera	3	4	12
Staphylinidae	10	3	5
Carabidae	5	1	9
Collembola	3	1	11
Janiridae	10	2	3
Hebridae	6		7
Ranidae			13
Tellinidae	2	10	1
Idoteidae	5	7	
Leptohyphidae	12		
Bopyridae		3	8
Tridactylidae	7	1	2
Cambaridae		7	2
Hydrometridae	6	1	1
Dytiscidae	3	1	3
Nemertea		7	
Acrididae	4		1
Bivalvia		1	4
Capitellidae	1	4	
Hemiptera	3	1	1
Macroveliidae	3		2
Oedicerotidae	3		2
Sminthuridae			5
Acarina	4		
Gyrinidae	3	1	
Hydrophillidae			4
Isopoda		4	
Mesoveliidae	3		1
Noteridae	4		
Plecoptera	3	1	
Pseudoscorpiones	1	3	
Rhynchobdellida			4

Appendix 9 (cont.)

Family	Garcitas Creek	Tres Palacios	Carancahua Creek
Chrysomelidae			3
Limnephilidae		3	
Panopeidae		3	
Pilargidae	3		
Pleidae	2	1	
Sipuncula			3
Tabanidae		3	
Tipulidae	2		1
Corydalidae		1	1
Gelastocoridae			2
Heteroptera	1	1	
Hirudinea			2
Melitidae			2
Nemata	2		
Phyllodocidae		2	
Pyralidae			2
Pyramidellidae		2	
Tetrigidae		2	
Veliidae		2	
Aeshnidae		1	
Ancinidae	1		
Anthuridae	1		
Anura	1		
Arthropoda		1	
Brachyura			1
Canaceidae	1		
Capitelllidae			1
Ellobiidae		1	
Helicopsychidae		1	
Heptageniidae			1
Hydraenidae	1		
Leptohyphiidae		1	
Naucoridae	1		
Protoneuridae			1
Taeniopterygidae		1	
Tunicata		1	
Unionidae			1