Coast-Wide Assessment of Texas Tidal Stream Communities

Prepared for
Texas Commission on Environmental Quality
in fulfillment of
Contract 582-8-80180

James Tolan

Texas Parks and Wildlife Department
4200 Smith School Road
Austin, Texas 78744

October 2008

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS

ANOSIM	Analysis of Similarity
DO	Dissolved Oxygen
MDS	Multidimensional Scaling
PSU	Practical Salinity Units
SIMPER	Similarity Percentage
SWQM	Surface Water Quality Monitoring
TCEQ	Texas Commission on Environmental Quality, formerly the Texas Natural Resource Conservation Commission
TDS	Total Dissolved Solids
TMDL	Total Maximum Daily Load
TOC	Total Organic Carbon
TPWD	Texas Parks and Wildlife Department
TSS	Total Suspended Solids
TWDB	Texas Water Development Board
UAA	Use Attainability Analyses
VSS	Volatile Suspended Solids

ACKNOWLEDGEMENTS

I would like to thank the Texas Commission on Environmental Quality, for providing funding for the completion of this project. Special thanks go to Jason Leifester, Chief Engineers Office, TCEQ, for shepherding the original UAA Studies, and believing enough in this new, multivariate analysis technique to allow this additional work to be performed. I would also like to thank Linda Broach for proving all the fishery and environmental data from the various TCEQ Studies in a readily accessible digital format. I would like to also acknowledge the many TPWD staff who participated on the Nueces Trawl Survey. This report represents the first place those data have been published. And a special thank you is reserved for Janet Nelson, my trusted colleague at TPWD. It is primarily through her tireless efforts, under occasionally hazardous field conditions, that I have the vast amount of ecological information available to me, allowing me to undertake this present work.

INTRODUCTION

Numerous tidal streams are included on the state's list of impaired water-bodies. 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 currently there is no standardized methodology for performing this assessment. TCEQ and TPWD have jointly recognized the need for developing a standardized, scientifically valid methodology for assessing the overall ecosystem health of tidal streams. A potential method, based on community-level assessments, was initially developed in the preparation of UAA reports for three tidal segments: Cow Bayou Tidal (Orange County), Tres Palacios Creek Tidal (Matagorda County), and Garcitas Creek Tidal (Jackson and Victoria Counties). Goals of these particular UAA studies included making recommendations regarding the appropriate aquatic life uses currently identified for Classified, as well as the numerous Unclassified Tidal Streams; and additionally, to uncover any biological evaluation criteria (biocriteria) for tidal streams that could have applicability over large spatial scales.

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 are 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) has been used to evaluate their attainment (TCEQ 2000). 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. The primary task of the UAA studies was to determine whether any differences in the physical, chemical, or biological components of ‘ecosystem health’ could be found between a reference and each of the study streams.

The choice of a reference stream is therefore critical in the context of evaluating designated uses, because historically, comparisons of ecological conditions within water-bodies has been evaluated against a similar reference water-body with minimal impacts. As there are likely few places along the Texas coast unaffected by anthropogenic disturbances, true reference conditions remain elusive. In general, the tidal stream UAA studies found little differences in any of the physical, chemical, or biological structures between the reference streams and any of the study streams (Tolan et al., 2007). Community-level indicators of ecosystem health generally involving upstream – downstream gradients that were primarily correlated with salinity structure; and these salinity-driven gradient conditions cut across all of the trophic levels of ecologic integrity. What was not seen was any clear separation of reference conditions and the “impaired or impacted” water-bodies, at any trophic level. As noted in Tolan et al. (2007), one of the drawbacks inherent in the “impacted vs. reference” pair-wise comparison approach is that with only two streams available for comparison, the actual differences between the reference condition and the “impacted” stream must be very large to show any clear difference. Therefore, the purpose of this study was to compile historical data sets from tidal streams and analyze them jointly with this new, standardized methodology. With a wide array of ecological conditions present in the present analysis, one goal of this study is to uncover biocriteria that may have general applicability over large spatial scales.

Five studies on tidal stream form the basis of the current work. TCEQ-1 (Guillen, 1996) sampled water quality, water chemistry, and nekton in Oyster Bayou, Dickinson Bayou, Texas City Pump Canal, Highland Bayou Diversionary Canal, and Cedar Lake Creek from June 1991 to September 1993. A second study performed by TCEQ (TCEQ-2; L. Broach, Texas Commission on Environmental Quality, unpublished data) sampled water quality, water chemistry, and nekton from Armand and Halls Bayous, from April 2002 until June 2003. Consultants for the City of Corpus Christi (APA, 1997) sampled water quality and nekton from the tidal portions of the Nueces, Aransas, and Mission Rivers, as well as from Bastrop and Chocolate Bayous during the summer of 1995. These collections represented one of the earliest studies of potential biocriteria in determining the appropriate aquatic life use designation for a tidal river segment. A second study on the Nueces River Tidal (TPWD, unpublished data; water quality and nekton sampling from October 1996 to November 2001) will be referred throughout as the Nueces Trawl Survey (NTS) The UAA Studies by TPWD (Tolan et al., 2007) involved water quality, water chemistry, and nekton collections from the tidal portions of Tres Palacios River, Garcitas Creek, the west fork of the Carancahua River, Lost River, and Cow Bayou.

Descriptions of Study Streams

Oyster Bayou

Segment 2423, tributary into East Bay, Chambers County (Fig. 1). Area 2423_01 (adjacent to the Intracoastal Waterway) was listed in 1998 for bacteria in oyster waters (TCEQ 2008). A total of five stations within Oyster Bayou were occupied for seine collections during June, September, and December of 1991; March and June of 1993; and February, May, July, and September of 1993. Three main stem stations (0.8 km upstream of the mouth of Oyster Bayou; 4.8 km upstream of the mouth; and 13.9 km upstream of the mouth) and two tributary stations (Umbrella Point Creek, 3.2 km east of the confluence of Oyster Bayou and East Bay; unnamed adjacent marsh, 6.4 km upstream of the mouth) were utilized. A total of 37 seine samples were collected from Oyster Bayou. The main stem stations were similar in their spatial configurations to the upper, middle, and lower stations that are used in all the other tidal stream studies. Trawl (N = 27), gillnet (N = 15), and limited electroshocking (N = 3) collections were made during these same calendar months, although trawling took place only on the main stem locations. Routine Field parameters (surface Temperature, Dissolved Oxygen, Specific Conductance, and Salinity), with the addition of bottom readings for D.O., Salinity, and Conductivity, were collected at each seine location. Conventional parameters collected included Ammonia Nitrogen, Nitrate+Nitrite, Orthophosphorus, Total Phosphorus, Chlorophyll a, Total Suspended Solids, and Total Organic Carbon. The land use around Oyster Bayou is predominantly agriculture, and this segment was classified by Guillen (1996) as pristine.

Dickinson Bayou

Segment 1103, from the confluence with Dickinson Bay 2.1 km downstream of SH 146 in Galveston County to a point 4.0 km downstream of FM 517 in Galveston County (Fig. 1). Areas' 1103_01 (from 4.0 km downstream of FM 517 to the Bordens Gully confluence), 1103_02 (from the Bordens Gully confluence to the Benson Bayou), and 1103_03 (from the Benson Bayou confluence to the confluence with Gum Bayou) were all listed in 1996 for bacteria and depressed dissolved oxygen. Sampling on Dickinson Bayou was done in conjunction with the efforts on Oyster Bayou, and five stations were also occupied for seine and water quality collections during March and June of 1993; and March, May, July, and September of 1993. No collections were made within this Segment during calendar year 1991. A total of 22 seine samples were collected from Dickinson Bayou. Three main stem stations (Dickinson Bayou at mouth, SH 416; 7.9 km upstream from the mouth at Gum Bayou; and 12.1 km upstream from the mouth) and two tributary stations (Factory Bayou at Fm 517; and Gum Bayou at FM 517) were utilized. The uppermost station on Dickinson Bayou was located in the Above Tidal portion (TCEQ Segment 1104) of this water-body. Trawl collections (N = 18) from the same calendar months each year were taken only on the main stem locations of this study stream. No gill net or electrofishing was performed on this tidal segment. The same suite of Field and Conventional parameters as those collected from Oyster Bayou were recorded from Dickinson Bayou. Predominant land use around Dickinson Bayou is agriculture/suburban.

Texas City Pump Canal

Segment 2439, Lower Galveston Bay (Fig. 1). Area 2439_01 (adjacent to the

Texas City Ship Channel and Moses Lake) was listed in 1996 for bacteria in oyster waters. The Pump Canal, originally identified as the Texas City Hurricane Canal in Guillen (1996), is an industrial canal that flows into the Texas City Ship Channel. The flow in this segment is characterized primarily by industrial treatment facilities, chemical plants, and stormwater discharged from a floodgate at the upstream extent. The area possesses little bank vegetation, and the majority of the canal possesses a steep slope (45-90 degrees) with the southern shoreline consisting of an artificial levee. An upper (located 3.2 km upstream of the mouth, downstream of the flood control gate), middle (1.6 km upstream of the mouth), and a lower (at the mouth) station were each occupied during March, May, July, and September of 1993 only. No sampling took place during either 1991 or 1992. Seine collections (N = 12) and water quality measurements were taken from each station. Trawl, gill net, or electrofishing events were not conducted within the Texas City Pump Canal. Guillen (1996) classified the Texas City Pump Canal as industrial/channel.

Highland Bayou Diversionary Canal

Segment 2424A, unclassified water-body, from confluence with Jones Bay to Avenue Q 0.5 miles (0.8 km) north of SH 6 between Arcadia and Alta Loma in Galveston County (Fig. 1). Area 2424A_01 (from the headwaters to FM 2004) was listed in 2002 for bacteria and depressed dissolved oxygen, whereas Areas' 2424A_02 (from FM 2001 to FM 519) and 2424A_03 (from Fairwood Road to Bayou Lane) were both listed in 2002 for bacteria. Like the Texas City Pump Canal, Highland Bayou Diversionary Canal is an artificial water-body created to aid in flood control. An upper (located 12.1 km upstream of the mouth, upstream of SH 6), middle (8.9 km upstream of the mouth, downstream of the Hitchcock municipal water treatment plant), and lower (mouth of Highland Bayou and Jones Bay/Intercoastal Waterway canal) station were occupied during March, May, July, and September of 1993 only. No sampling was conducted during 1991 or 1992. Only seining (N = 12) and trawling (N = 12) efforts took place on this tidal segment, with water quality measurements collected in conjunction with the seine samples. The land use around this man-made water-body has been classified as suburban/flood control (Guillen, 1996).

Cedar Lake

Segment 2442, Cedar Lakes Creek, Brazoria County (Fig. 1). Area 2442_01 (entire segment) was listed in 1998 for bacteria in oyster waters. Three main stem stations were occupied during March, May, July, and September of 1993. No sampling took place during 1991 or 1992. The upper station was located 16.1 km upstream of the mouth near FM 2611. The middle station was located 11.3 km upstream of the mouth, near the San Bernard Wildlife Management Area boat ramp. The lower station was located approximately 3.2 km upstream of the junction of the mouth and the Intracoastal Waterway canal. Seine collections (N = 9), in concert with the Field and Conventional water quality parameters took place at each station. Twelve trawl samples were collected from the upper and lower stations, whereas four gill net samples were collected from the middle and lower stations. The land use around Cedar Lake is predominantly agriculture, and this segment was also classified by Guillen (1996) as pristine.

Armand Bayou

TCEQ Segment 1113, from the confluence with Clear Lake (at NASA Road 1 bridge) in Harris County to a point 0.8 km downstream of Genoa-Red Bluff road in Pasadena in Harris County (includes Mud Lake, see Fig. 1). Within this Segment, Areas' 1113_01 (upper segment boundary to confluence with Big Island Slough) and 1113_02 (Big Island Slough confluence to Horsepen Bayou confluence) were both listed for depressed dissolved oxygen in 1996. Area 1113_02 was additionally listed for bacteria in 2006. Biological sampling for nekton, consisting of trawl (N = 2), seine (N = 9), and electroshocking (N = 4), were conducted at an upper, middle, and lower station in April and August of 2002, and again in June of 2003. Water quality collections of routine Field, and full suite of Conventional (BOD, Ammonia Nitrogen, Nitrate+Nitrite, Total Kjedahl Nitrogen, Orthophosphorus, Total Phosphorus, Chlorophyll a, Phaetophytin, Total Suspended Solids, Volatile Suspended Solids, Total Dissolved Solids, Chloride, Sulfate, Flouride, Alkalinity, and TOC) parameters were collected at each station on these same dates.

Halls Bayou

Segment 1006D, Unclassified water body. Perennial stream from the confluence with Greens Bayou up to US 59 in Harris County (Fig. 1). Areas' 1006D_01 (from the confluence with Greens Bayou to US 59) and 1006D_02 (from Hirsch Road to Homestead Road) both listed for bacteria in 2002. Nekton sampling with trawl (N = 4), seine (N = 9), and electroshocking (N = 4) were conducted in conjunction with the study at Armand Bayou. Sample sites at an upper, middle, and lower station were occupied in May and July of 2002, and again in June of 2003. Routine Field and Conventional parameters were also collected at each station on these dates.

Nueces River Tidal

Segment 2101, from the confluence with Nueces Bay in Nueces County to

Calallen Dam 1.7 km upstream of US 77/IH 37 in Nueces/San Patricio County (Fig. 1). Segment 2101 is not currently listed for any impairments or concerns. Two different studies have taken place on the Nueces River Tidal segment. The first was a study focusing on nekton collections with both seines and trawls, conducted in the summer of 1995. Three stations (an upper one located at the IH 37 bridge; a middle one at the confluence with a minor tributary 2.4 km upstream of the Allison Wastewater Treatment Plant; and a lower one 1.6 km downstream of the Union-Pacific Railroad bridge) were occupied during 31 July – 3 August and then these same stations were revisited during 5 – 7 September. Depth profiles of D.O., temperature, specific conductance, pH, Secchi depth, and current velocity were recorded from three locations during the July/August sampling trip: midchannel, right quarter point, and left quarter point. Depth profiles during the September sampling event was reduced to midchannel only. Nekton sampling consisted of otter trawls (N = 6) and bag seines (N = 6). No Conventional parameters were collected during this study.

The second study on the Nueces River Tidal segment was a trawl-only study conducted by TPWD from October 1996 to November 2001. Monthly samples were collected in each spring and summer season, with alternating months' samples collected during the fall and winter seasons. With each collection, profiles of routine Field parameters were collected. No Conventional parameters were collected during this study. The three station locations used for the TPWD trawl study closely matched those locations established by the previous study. A total of 130 trawl samples were collected during this study.

Mission River Tidal

Segment 2001, from the confluence with Mission Bay in Refugio County to a point 7.4 km downstream of US 77 in Refugio County (Fig. 1). Area 2001_1 (entire segment) was listed in 2004 for bacteria. Sampling on the Mission River Tidal was conducted in conjunction with the earlier study on the Nueces River Tidal (APA, 1997), with all the collections taking place during August and September 1995. The upper station was located 1.6 km upstream of the confluence with Sous Creek; the middle station was located 2.4 km upstream of the confluence of an unnamed tributary and approximately 4.3 km upstream of the FM 2678 bridge; and the lower station was located at the confluence with a minor tributary 2.1 km downstream of the FM 2678 bridge. Depth profiles, as well as trawl (N = 6) and seine (N = 6) samples were collected at each station. No Conventional parameters were collected during this study.

Aransas River Tidal

Segment 2003, from the confluence with Copano Bay in Aransas/Refugio County to a point 1.6 km upstream of US 77 in Refugio/San Patricio County (Fig. 1). Area 2003_1 (entire segment) was listed in 2004 for bacteria. Elevated levels of Nitrate and Orthophosphorus were identified as a Concern within this segment (NRA 2007). Sampling took place during the summer of 1995, with three stations occupied in August and an additional station added during the September sampling event. The uppermost station (added during the follow-up sampling in September) on this segment was located 8.7 km upstream from the confluence with Chiltipin Creek. The upper station extended from the confluence with an unnamed branch of Chiltipin Creek to a point 1.6 km downstream at the confluence with a minor tributary. The middle station extended 0.8 km upstream and downstream of a small, unimproved road bridge; and the lower station was located at the confluence with Chilitpin Creek. Depth profiles, as well as trawl (N=6) and seine (N = 6) samples were collected at each station. Sample size of nekton collections (N = 6 for both trawl and seine collections) from the Aransas Tidal segment matches the remainder of the tidal streams included in this investigation (Nueces, Mission, Bastrop, and Chocolate) because the middle station on the Aransas Tidal was dropped in favor of a more-uppermost station on the subsequent sampling trip in September 1995. No Conventional parameters were collected during this study.

Bastrop Bayou

Segment 1105, from the confluence with Bastrop Bay, 0.77 km downstream of the Intracoastal Waterway in Brazoria County to the Missouri-Pacific railroad at Lake Jackson in Brazoria County (Fig. 1). Segment 1105 is not currently listed for any impairments or concerns. Sampling on Bastrop Bayou took place during the summer of 1995, with three stations occupied in both August and September. The upper station was located 0.8 km downstream from Business SH 288 bridge; the middle station at 0.6 km upstream from the CR 277 bridge; and the lower station was at the confluence at the Intracoastal Waterway Canal. Depth profiles, as well as trawl (N = 6) and seine samples (N = 6) were collected at each station. No Conventional parameters were collected during this study.

Chocolate Bayou

Segment 1107, from the confluence with Chocolate Bay, 1.4 km downstream of FM 2004 In Brazoria County to a point 4.2 km downstream of SH 35 in Brazoria County (Fig. 1). Segment 1107 is not currently listed for any impairments or concerns. Sampling on Chocolate Bayou also took place during the summer of 1995, with three stations occupied in both August and September. The upper station was located at the confluence with the Chocolate Bayou Rice Canal; the middle station began at the confluence of Pleasant Bayou; and the lower station was located 0.6 km downstream from FM 2004. Depth profiles, as well as trawl (N = 6) and seine samples (N = 6) were collected at each station. No Conventional parameters were collected during this study.

Cow Bayou Tidal

Segment 0511, from the confluence with the Sabine River in Orange County to a point 4.8 km upstream of IH 10 in Orange County (Fig. 1). The lower part of Cow Bayou Tidal was channelized in the early 1950's for navigation, leaving numerous side channels and oxbows. Segment 0511 is not currently listed for any impairments or concerns. Sampling on Cow Bayou took place from April 2003 until November 2004, as part of the tidal stream UAA studies. Four stations were occupied seasonally during this study, with the exception of winter, when no sampling took place. The upper station was located at the Cole Creek confluence and the middle station was located at the SH 87 bridge. A second middle station was located approximately 2.2 km upstream of SH 87, in the original stream channel northeast of Bridge City. This station was occupied in order to document any differences in ecosystem health between the natural and channelized portions of the Segment. The lower station was located 0.7 km upstream of the confluence with the Sabine River. Trawling was performed on the middle and lower stations only, with a total of 34 samples collected. Seine collections were performed at every station, for a total of 48 collections. Gill net (N = 48) and electrofishing efforts (N = 48) were also part of this study. Each sampling event also recorded depth profiles of routine Field parameters, as well as the full suite of Conventional parameters.

Lost River Tidal

Segment 0801A, unclassified water body, from IH 10 in Chambers County to approximately 6 km upstream of confluence with John Wiggins Bayou in Chambers and Liberty Counties (Fig. 1). Segment 0801A is not currently listed for any impairments or concerns. Although Lost River has a well-defined channel, there are numerous connections with nearby water bodies, including the Trinity River and backwater areas. At its upper end, Lost River is plugged by an earthen dam that was constructed to prevent salt water from contaminating upstream drinking water supplies. Approximately 6.4 km downstream, Lost River opens into Old River Lake, the point considered the mouth of the stream for purposes of the UAA study. Sampling on Lost River took place from April 2003 until November 2004. Three stations were occupied seasonally during this study, with the exception of winter, when no sampling took place. The upper station was located 0.40 km upstream of the Chambers County line, 5.4 km upstream of John Wiggins Bayou confluence. The middle station was 2.6 km upstream of the confluence with John Wiggins Bayou, northeast of Lost Lake oil field. The lower station was located at confluence with Old River Lake, 1.3 km upstream of IH-10. Trawling was performed at all the stations, with a total of 34 samples collected. Seine collections were performed at every station, for a total of 36 collections. Gill net (N = 36) and electrofishing efforts (N = 36) were also part of this study. Each sampling event also recorded depth profiles of routine Field parameters, as well as the full suite of Conventional parameters. Lost River Tidal was the reference stream for the upper coast tidal UAA study.

Garcitas Creek Tidal

Segment 2453A, from the confluence of Lavaca Bay in Jackson County to a point 8.5 miles upstream of FM 616 in Jackson County (Fig. 1). The tidally-influenced portion of the stream extends just upstream of its confluence with Arenosa Creek. The entire segment was initially listed for depressed dissolved oxygen in 1995, and it remains on the impaired waterbody list for this same parameter. Sampling on Garcitas Creek took place from April 2003 until November 2004, as part of the UAA study. Three stations were occupied seasonally during this study, with the exception of winter, when no sampling took place. The upper station was located approximately 3.1 km upstream of FM 616; the middle station was 1.80 km downstream of FM 616; and the lower station was 6.5 km downstream of FM 616. Trawling was performed at all the stations, with a total of 36 samples collected. Seine collections were performed at every station, for a total of 36 collections. While gill net (N = 35) collections were made on this Segment, electrofishing was not included as the salinities were routinely too high for this gear to be operated effectively. Each sampling event also recorded depth profiles of routine Field parameters, as well as the full suite of Conventional parameters.

Tres Palacios Creek Tidal

Segment 1501, from the confluence with Tres Palacios Bay in Matagorda County to a point 1.0 km upstream of the confluence of Wilson creek in Matagorda County (Fig. 1). In 1996, Area 1501_01 (entire segment) was listed for depressed dissolved oxygen, and in 2006, this same area was listed for bacteria. Sampling on Tres Palacios took place from April 2003 until November 2004, as part of the UAA study. Three stations were occupied seasonally during this study, with the exception of winter, when no sampling took place. The upper station was located 1.5 km upstream of the confluence of Wilson's Creek; the middle station was 3.75 km upstream of SH 521, northeast of the city of Palacios; and the lower station was approximately 7.5 km downstream of SH 521. Trawling was performed at all the stations, with a total of 33 samples collected. Seine collections were performed at every station, for a total of 34 collections. While gill net (N = 35) collections were made on this Segment, electrofishing was not included on this Segment due to high salinities. Each sampling event also recorded depth profiles of routine Field parameters, as well as the full suite of Conventional parameters.

West Carancahua Creek Tidal

Segment 2456A, from the confluence with Carancahua Bay in Jackson County to Jackson CR 440, 10.1 km upstream of FM 616 in Jackson County (Fig. 1). Area 2456A_01 (entire water body) was listed in 2006 for depressed dissolved oxygen. Sampling on West Carancahua took place from April 2003 until November 2004. Three stations were occupied seasonally during this study, with the exception of winter, when no sampling took place. The upper station was located approximately 5.1 km upstream of the confluence with East Carancahua Creek; the middle station was approximately 1.9 km upstream of the confluence with East Carancahua Creek; and the lower station was 4.5 km downstream of the confluence with East Carancahua Creek. Trawling was performed at all the stations, with a total of 33 samples collected. Seine collections were performed at every station, for a total of 36 collections. While gill net (N = 32) collections were made on this Segment, electrofishing was not included on this Segment due to high salinities. Each sampling event also recorded depth profiles of routine Field parameters, as well as the full suite of Conventional parameters. West Carancahua Tidal was the reference stream for the mid-coast tidal UAA study.

Assessment Methodology

The multivariate 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 Contreras et al. (2005). Schematically, these methods are shown in Fig. 2. In Part A, MDS procedures are used to identify the configurations of the different datasets (e.g., biological, physiochemical, habitat. etc.). Distinction among stations (in terms of their biological communities, and their physical and chemical properties), as well as the differences among them, 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 “pictures”. Spearman’s rank correlation is used to quantify the degree of agreement between the independent datasets (in Fig. 2, designation of 1, 2, and 3 in the hypothetical MDS plots represent multiple stations on the various steams). The natural separation of the “biological” and the “physical and/or 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 among the study streams are evaluated 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.

What was not seen in the UAA studies were clear separations of the reference streams from the "impaired or impacted" streams, at any level of ecosystem health. Conceptually, if the impacted streams are clearly different from the reference condition, then the multivariate ordination techniques used for these studies should be able graphically illustrate these differences (see Fig. 3). In this hypothetical example, the reference stream (Exceptional Aquatic Life Use designation, Stream A) clearly has different biological constituents 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. 3). The goal of the present study is to apply the outlined multivariate techniques to a number of historical datasets collected from varying degrees of "impacted" tidal streams; and determine to what extent the biological communities among these streams can be used to determine tidally-influenced biocriteria with spatial applicability.

RESULTS

Because of varying amounts of sampling efforts amongst the studies, the Results presented here are limited to common collections across all studies. Surface water quality and chemistry measurements are compared to bag seine collections, as this gear records nekton from the surface margins of tidal streams. Bottom water quality measurements are compared to the otter trawl collections, as this gear samples nekton from the middle of the tidal stream. Nekton recorded with gill nets and electroshocking efforts were not analyzed, due to the very limited spatial and temporal coverage across the various studies.

Physical Properties – Surface Collections

For each study stream, total collections were first reduced to only those sampling events that took place during the seasons of spring (March - May), summer (June – August), and fall (September – November). While this had the effect of lowering the overall sample size of the collections to N = 318, this was done in order to have the greatest consistency in any comparisons among the spatially and temporally disjunct studies. Surface measurements of the routine Field parameters collected are summarized in Table 1, and their MDS configuration is shown in Fig. 4. Comparing Fig. 4 to the idealized MDS configuration of Fig. 2, no individual tidal stream clearly separates from the remainder, although Cow Bayou does appear to be the most distinct and form one of the most internally cohesive groupings. While the ANOSIM test revealed that there were significant differences among the physical characteristics of these different systems (Global R = 0.285, $p < 0.001$), there was a great degree of overlap that cut across any latitudinal gradients along the coast (Fig. 5). Comparisons between all other streams and Cow Bayou each had significant R statistics values ranging from 0.323 (Garcitas Creek) to 0.783 (Highland Bayou Diversionary Canal). At a Euclidean Distance of 0.3, a general grouping of the UAA study streams plus Oyster Bayou clearly separated from the remainder of the TCEQ and APA studies. Surface water Physical properties at Dickinson Bayou were similar to conditions found within each of the major groupings of studies, and this stream cut across the two large groups. No group of stations (enclosed within a common ellipse) showed any geographical distinctness, with upper coast stations such as Oyster Bayou, Dickinson Bayou, and Halls Bayou having similar Physical properties to Chocolate Bayou, Tres Palacios, and Garcitas Creek.

The parameter most influential in separating out the groups of stations was Salinity (Fig. 6). The gradient of lowest salinities in Cow Bayou and Lost River to the highest salinities in Highland Bayou Diversionary Canal and Aransas River Tidal is shown in Fig. 6a. To a lesser extent, surface Temperature readings were also influential in the MDS configuration, but it should be noted that the systems with the highest surface temperatures (Aransas, Nueces, Bastrop, Chocolate, Mission, Armand, and Halls) were all studies that had severely limited seasonal sampling (Fig. 6b). Collections from each of these streams all came in the summer season. Mean dissolved oxygen readings were above the threshold value for tidal streams with a High Aquatic Life Use designation, ranging from a high of 9.02 mg/l on the Aransas River to a low of 5.05 mg/l on Cow Bayou (Fig. 6c).

Chemical Properties – Surface Collections

Water chemistry measurements were not collected during the APA or the TPWD NTS studies, therefore the streams utilized for these studies are not included in the analysis of surface Conventional parameters. The remaining streams had varying levels of effort in the suite of Conventional parameters collected, with the common parameters of Ammonia, Orthophosphate, Total Phosphorus, Chlorophyll a, Total Suspended Solids, and Total Organic Carbon recorded from each stream. These parameters are summarized in Table 2, and their MDS configuration by stream is presented in Figure 7. Surface water chemistry was not markedly different among the majority of the tidal streams, save for Texas City Pump Canal and Tres Palacios River. All other streams clustered in a relatively small area within the chemical constituent-based MDS of Fig. 7. ANOSIM revealed a significant difference among the streams (Global R = 0.271, $p < 0.001$), with Texas City Pump Canal and Lost River being clearly different in term of their surface water chemistry (Fig. 8). Similar to the MDS configuration of the Physical properties, most of the tidal streams showed a great degree of overlap in the chemical properties of their surface waters. Groupings of similar streams are also not apparently linked to their physical location along the coast. Nutrient loading and TSS were identified as the parameters most influential in separating out like streams. The Texas City Pump Canal had excess nitrogen and phosphorus constituents, while Tres Palacios Tidal had the highest levels of Total Suspended Solids.

This evidence of eutrophication within Texas City Pump Canal is shown in Fig. 9. Order of magnitude increases in nutrients (Ammonia, Orthohosphate, and Total Phosphorus) apparently fueled greatly increased primary production within this stream. Chlorophyll-a concentrations within the Texas City Pump Canal ranged from 3.1 to 15.1 times higher than any other tidal stream under investigation.

The correlation between the MDS configurations of the Physical properties and the Chemical properties of the surface waters was quite high, with a Spearman's ρ value of 0.521 ($p = 0.007$).

Nekton Communities – Bag Seine Collections

The level of effort in the seine collections differed greatly among the studies, both in terms of the seasonal coverage between each study, all the way to the equipment used within each study. Collections for the TCEQ-1 work on Oyster Bayou, Dickinson Bayou, Texas City Pump Canal, Highland Bayou Diversionary Canal, and Cedar Lake Creek included sampling events across all four seasons, yet each season was not replicated within each location. The equipment used for this study was far more consistent, in that at each station a 15 X 4 foot straight seine with 1/8th inch square mesh was used. The catch from five replicate hauls of 25 linear feet of shoreline each were pooled, for a combined catch per 125 feet.

Sampling for the TCEQ-2 study on Armand and Halls Bayous' only covered the spring and summer seasons, with each season replicated over two calendar years. A straight seine (15 X 4 foot with 3/16th inch mesh) was used to cover 125 feet of shoreline per sample (five replicate hauls of 25 ft each). Total catch for all replicates were pooled.

The APA study on the Nueces, Mission, and Aransas Tidal, as well as Bastrop and Chocolate Bayous' had the least amount of temporal coverage, with only summer sampling events within a single calendar year. The gear used in this study was the most variable, with the initial sampling (July and August, 1995) consisting of a 15 X 5 foot, 3/16th inch mesh straight seine used on Bastrop and Chocolate Bayous'; whereas a 30 X 6 foot, 1/8th inch mesh bag seine (6 X 6 foot bag located in the middle of the net) was used on the Nueces, Mission, and Aransas Tidal segments. For the second sampling event (September, 1995), each stream was sampled with the 15 X 5 foot, 3/16th inch mesh straight seine. Sampling was designed so each seine event covered an area between 2,000 and 2,700 square feet. Each sample covered between 133 and 180 linear feet of shoreline.

The UAA sampling conducted on Tres Palacios, West Carancahua, and Garcitas Creek utilized a 30 X 8 foot straight seine with 3/16th inch mesh. Because of a narrow shelf and a steep channel profile on the side of many of the sampling stations, most areas were too deep to wade the deep end of the seine. In those cases, one end of the seine was either walked or held against the bank and the seine was deployed perpendicular to the shore with a boat, then maneuvered back in an arc towards the shore with the boat. At each sampling location, seine pulls were repeated until a linear distance of 125 feet of shoreline had been covered. On Cow Bayou and Lost River, a 10 X 6 foot straight seine with 3/16th inch mesh was used. Multiple seine hauls were taken at each station until the seine covered a total of 125 linear feet of shoreline. Temporally, the UAA studies covered the seasons of spring, summer, and fall, with each season replicated twice for each of two calendar years.

The MDS configuration of the bag seine collections from each stream is shown in Fig. 10. Missing from Fig. 10a is any clear indication of a tidal stream community dramatically different from the remainder, as hypothesized in the "impaired" stream shown in Fig. 2. Like the MDS configuration of the Physical properties, the community-based analysis again showed that Salinity was also an important factor in structuring the nekton (Fig. 10b). Differences in the level of effort are evident in the total catches recorded by each study, which is summarized in Table 3. Order of magnitude differences in total catch existed between the studies, although the number of taxa encountered in each study was far more equitable. Even across the varying salinity gradients, very similar nekton communities were found in each tidal stream. SIMPER analysis revealed that between 71.9 and 96.0% of the total collections were dominated by only six taxa common to each stream: bay anchovy (*Anchoa mitchilli*), white shrimp (*Litopenaeus setiferus*), grass shrimp (*Palaemonetes spp*.), silversides (a mixture of *Menidia spp.* and *Membras martinica*), blue crab (*Callinectes sapidus*), and

Gulf menhaden (*Brevoortia patronus*).

In order to directly compare these vastly different studies with a uniform Assessment Methodology, the data from each study was first standardized to a unit effort of "catch per 125 linear feet of shoreline". Seasonal comparisons among the streams were further reduced to collections taken during the summer. This reduction of the nekton community data to the summer-only period is reflective of the UAA study results, in that communities recorded in the spring and fall were the most temporally distinct, while the summer collections typically encompassed taxa that ranged across the seasons under consideration in the present studies (spring, summer, and fall). Despite these limitations, the analysis of the community structure found in all the tidal streams during summer showed that the water quality and water chemistry characteristics that defined the most "impacted" streams did not necessarily translate to an "impaired" condition in the biota (Fig. 11). Analysis of Similarity found significant differences in the community composition among the tidal segments (Global R = 0.285, $p < 0.001$), with Cow, Halls, Bastrop, and Chocolate Bayous' having the most distinct nekton communities (Fig. 12a). When reduced to the summer-only seasonal period, salinity was not as an influential Physical parameter in separating out groups of stations when compared to the full collections (Fig. 12b). None of the truly "impacted" streams (Texas City Pump Canal, Highland Bayou Diversionary Canal, or Dickinson Bayou) had a community structure dramatically different from the more pristine streams on either the mid-coast (Garcitas Creek, Mission River, or Aransas Rivers) or the upper-coast (Cedar Lake Creek, Lost River, or Oyster Bayou).

Overlaying the standardized abundance levels of the six most abundant taxa onto the MDS configuration of the bag seine communities helps to reveal some of the reasons why Cow, Halls, Bastrop, and Chocolate Bayous' were identified as being unique (Fig. 13). Bay anchovy made up a very low percentage of the communities at Halls, Bastrop, and Chocolate Bayous', whereas white shrimp dominated the catches at Bastrop and Chocolate Bayous' (Table 4). Conversely, white shrimp made up a conspicuously small portion of the community at both Halls and Cow Bayous'. Taxa that helped to define Cow Bayou as the most unique community (significant R statistic values ranged from R = 0.398 vs. Tres Palacios to R = 0.615 vs. Cedar Lake Creek) included a number of freshwater fish that were not major components of the communities recorded at any of the other tidal streams (bluegill, *Lepomis macrochirus*; largemouth bass, *Micropterus salmoides*; and redear sunfish, *Lepomis microlophus*, see Table 4). Similarly, the freshwater taxa spotted sunfish (*Lepomis punctatus*) was identified as a large component of the community at Halls Bayou, where a significantly different nekton community was also recorded.

These overlays also reveal some potential systematic bias that could be the result of the various sampling protocols employed amongst the studies. Generally, the TCEQ studies over-represented taxa with the highest affinity for structured habitat (white shrimp, grass shrimp, blue crab, and silversides, see Fig. 13), whereas the UAA and APA studies over-represented the pelagic components of the community (bay anchovy and Gulf menhaden). Grass shrimp were a conspicuous part of the community at Halls Bayou, whereas these same taxa were relatively rare from Cow, Bastrop, or Chocolate Bayous'. Cow Bayou generally had the lowest abundance of most of the common estuarine taxa, which could be the result of the low salinities found on this stream (Fig. 6). While Lost River had a similar salinity regime as was found on Cow Bayou, it generally had higher abundances of estuarine taxa than those found in the surface waters of Cow Bayou (e.g., Gulf menhaden, grass shrimp, and pinfish, see Table 4).

The correlation between the biological-based MDS configurations and those of the Physical properties (Spearman's $\rho = 0.033$, $p = 0.389$) and the Chemical properties (Spearman's $\rho = 0.038$, $p = 0.380$) during the summer-season was low, with neither correlation being significant. The concept of an "impacted" stream, as measured by traditional water quality parameters, was not replicated by an analysis of the community structure in the surface waters as recorded by bag seines.

Physical Properties – Bottom Collections

Bottom measurements of the routine Field parameters are summarized in Table 5, and their MDS configuration is shown in Fig. 14. Comparing Fig. 14 again to the idealized MDS configuration of Fig. 3, the uppermost stations on the coast (Cow Bayou) appears to clearly separate from the lowermost stations on the coast (Nueces River Tidal segment). Bottom water measurements were less variable that the surface measurements, with Cow Bayou, Lost River, and Aransas River forming the most internally cohesive groupings. The ANOSIM test revealed that there were significant differences among the Physical characteristics (Global R = 0.055, $p < 0.021$), with the great degree of distinctness occurred between the rivers with the largest differences in salinity gradients (Cow Bayou vs. Armand Bayou, Aransas River Tidal, and Highland Bayou Diversionary Canal; R > 0.882 in each case). These significant differences in bottom water Physical properties are shown in Fig. 15. As was the case with the surface measurements, there was little geographical distinctness to the MDS configuration (i.e., Cedar Lakes Creek, Armand Bayou, and Mission River Tidal had similar physical properties to other bayous up and down the coast; Dickinson Bayou, Bastrop Bayou, and the highly modified Highland Bayou Diversionary Canal). Three distinct groups of stations were defined from the ANOSIM procedure, with a geographical mix of tidal stream comprising each group, save for the single station of Cow Bayou that was identified as the most distinct. The Chemical constituents' groupings were similar to the Physical groupings, in that the UAA study streams with the addition of Oyster Bayou clearly separated from the remainder of the TCEQ and APA studies.

Salinity was again the parameter most influential in separating out the groups of stations (Fig. 16). Unlike the surface measurements, bottom water temperature readings were much less influential in the positioning of each stream in the MDS configuration. Most rivers had dissolved oxygen readings above the threshold value for a High Aquatic Life Use designation, but depressed D.O. readings in the bottom waters were evident in West Carancahua, Bastrop and Chocolate Bayous, as well as the Highland Bayou Diversionary Canal (see Table 5).

The correlation between the MDS configurations of the bottom and surface water Physical properties (Spearman's $\rho = 0.65$, $p < 0.001$) as well as the bottom water Physical properties and surface water Chemical properties (Spearman's $\rho = 0.567$, $p < 0.003$) were both highly significant. Even though the water column was stratified with regards to some parameters (i.e., D.O. and temperature), salinity was uniformly the parameter most influential in separating groups of similar streams. These salinity gradients were also important in the bottom waters throughout any latitudinal differences measured along the coast.

Nekton Communities - Trawl Collections

The efforts in the trawl collections were more uniform, in terms of the equipment used amongst the studies. Temporally, the seasons that trawl operations were conducted were the same as with the bag seines. The TCEQ-1 study utilized a 10 foot otter trawl with 1 inch mesh in the wings and 1/4 inch mesh in the cod end. Four, 5 minute replicate trawls were made at each of the upper, middle, and lower station on each stream. Due to numerous obstructions, trawling was not performed on the lower station of Cedar Lake Creek. Additionally, no trawling was performed on any station in the Texas City Pump Canal.

Sampling for the TCEQ-2 study also used a 10 foot otter trawl with 1 inch mesh in the wings and 1/4" mesh in the cod end. Four replicate tows of 5 minutes each was performed the upper, middle, and lower stations. Total catch for all replicates were pooled by station.

The APA study on the Nueces, Mission, and Aransas Tidal, as well as Bastrop and Chocolate Bayous' used a 10 foot with 1 inch mesh in the wings, with a 0.2 inch mesh sock (insert) in the cod end. For this study, only three replicate 5 minute trawls at 1100 constant engine revolutions per minute were conducted at each station. Nekton from each 5 minute trawl was combined into a single container.

The Nueces River trawl survey (NTS) conducted by TPWD used gear similar to the APA study, utilizing a 10 foot otter trawl with 1 inch mesh in the wings and a 0.2 inch mesh sock (insert) in the cod end. The speed of trawling for the NTS study was slightly higher than that used for the APA study, with a goal of 1300 constant engine revolution per minute. This study also use three replicate 5 minute trawls at each station, and the total catch from each replicate pooled.

Trawling for the UAA study was conducted with a 10 foot otter trawl with 1 inch mesh in the wings and a 0.2 inch mesh sock (insert) in the cod end. Sampling consisted of three 5-minute intervals at constant engine speed of 1300 revolutions per minute. There were problems with snagging woody debris throughout this 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. Due to repeated snags, trawling efforts were suspended at the upper-most station on Cow Bayou during the initial sampling efforts of the UAA Study. In all other cases, trawling was completed at each upper, middle, and lower station for this study.

The MDS configuration of the complete trawl collections are presented in Fig. 17. The nekton communities recorded by this gear also lacked the clear differences hypothesized in Fig. 2. Unlike the MDS configuration of the full bag seine collections, the community-based analysis of trawl catches showed that Salinity was far less important in structuring the nekton. A difference in the level of effort amongst the studies was also evident in the trawl catches (Table 6). While order of magnitude differences in total catch were encountered among studies, the number of taxa encountered in each study was generally similar. Nekton communities in each stream were similarly dominated by only a few individuals, with SIMPER analysis revealing that 64.2 to 96.2% of the individuals came from six taxa common to each tidal system: white shrimp (*Litopenaeus setiferus*), blue catfish (*Ictalurus furcatus*), bay anchovy, Gulf menhaden, Atlantic croaker (*Micropogonias undulatus*), and spot (*Leiostomus xanthurus*, see Table 7).

Analysis of the summer-season community structure (Fig. 18) recorded with otter trawls revealed significant differences among the streams (Global R = 0.367, $p < 0.001$), with Oyster Bayou identified as the most distinct (Fig. 19). Again, none of the water quality “impacted” streams (Texas City Pump Canal, Highland Bayou Diversionary Canal, or Dickinson Bayou) had nekton communities dramatically different from any of the more pristine systems. Overlaying the standardized abundance levels of the six most common taxa onto the MDS configuration of the otter trawls also revealed potential systematic bias among the studies. Most of the UAA study locations were significantly different from the other earlier studies (except for Cow Bayou bridging the gap between the UAA locations and the remainder of the study streams). The TCEQ studies again over-represented particular taxa (white shrimp, Atlantic croaker, and spot), whereas the UAA and APA studies over-represented the more pelagic taxa (bay anchovy and Gulf menhaden, see Fig. 20). Oyster Bayou was identified as having the most unique community, characterized by mainly by large percentages of blue crab, Atlantic croaker, and white shrimp. Missing from the communities recorded on Oyster Bayou were large concentrations of bay anchovies, an important member of the communities recorded from all other tidal streams included in this study.

The correlation between the summer-season otter trawl MDS configurations and bottom-water Physical properties was significant (Spearman's $\rho = 0.234$, $p = 0.001$).

Measures of Taxonomic Diversity

Taxonomic diversity and distinctness tests address some of the shortcomings identified with species richness as well as other diversity indices, in that they are based not just on species abundances, but also on the taxonomic distances through a phylogenetic classification tree between every pair of individuals (see Clarke and Warwick, 2001 as well as Contreras et al., 2005 for further explanations of these taxonomic-based measures). One of the qualities of these diversity measures 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, or more importantly for the present study, for comparing different studies for which the sampling effort is unequal or uncontrolled. Primarily, average taxonomic distinctness (Delta$^+$) is the average taxonomic distance apart of all its pairs of species present in a sample. This measure can be thought of as the average taxonomic breadth of the sample, or collection of samples. Variation in taxonomic distinctness (Lambda$^+$) captures the variance of the taxonomic distances between each pair of species about their mean value (Delta$^+$). This statistic (Lambda$^+$) can help to distinguish underlying differences in taxonomic structure resulting from assemblages with equivalent average taxonomic distinctness (similar numbers of total taxa) in which a few genera are represented by highly species-rich assemblages and the remainder of other higher taxa are represented by only a few taxa. Lower values in Lambda$^+$ equates to consistent taxonomic tree construct lengths between taxa, whereas higher values are can be found in more disparate tree configurations among the taxa.

Using the species lists from the five different studies under consideration as the master species list, a total of 191 unique taxa have been encountered in tidally influenced systems along the Texas coast. The taxonomic groupings used for the master species list were: species, genus, family, order, class, and phyla; with equal step lengths between adjacent taxonomic levels of 16.67 (species within different phyla therefore would be at a taxonomic distance of ω= 100). Figure 21a displays the funnel plot for the bag seine collections, catering for all sublist sizes up to 100 species. The simulated 95% probability limits, based on 999 random selections for each sublist size up to 100, is also shown. Mean taxonomic distinctness ($Delta^+$ = 73.4) is relatively constant at samples size greater than 20, and this diversity level equates to class and order level differences. The limits become increasingly wide as sample size decreases, reducing the likelihood of being able to detect a change in distinctness in species poor collections.

From Fig. 21a, systematic biases among the studies uncovered in the MDS configurations are again quite evident. The lowest degree of taxonomic diversity was recorded in the temporally limited APA study, where the summer-only sampling recorded between 23 and 27 taxa from each of those streams. Collections from the Mission River were more diverse than expected, whereas those from Chocolate Bayou were far less diverse than would be expected. Both TCEQ studies recorded communities that were lower than expected in terms of their average taxonomic diversity, with Halls Bayou (p = 0.038) and Oyster Bayou (p = 0.018) falling below the 95% probability limit. Both Halls and Oyster Bayous' were identified in their respective studies as either a pristine segment, or was used as a reference condition. All the UAA study streams fell within the expected range of taxonomic diversity, although the diversity at Cow Bayou (p = 0.082) was much lower than the remainder of the streams utilized for this study. Variation in taxonomic diversity was greatly increased in both the Mission River and Bastop Bayou (Fig. 21b), although both streams were within the 95% probability limits. Taxonomic variation was lowest in Oyster Bayou, but again, it was well within the expected region of Fig. 21b.

Average taxonomic distinctness (Delta+ = 75.3) for the trawl collections is shown in Fig. 22a. Like the seine collections, the APA study generally collected the fewest taxa (ranging between 11 and 28), although the TCEQ-2 study on Halls and Armand Bayou also collected fewer than 15 unique taxa. The trawl collections at Cedar Lake (p = 0.028) were significantly lower in diversity than would be expected. Cedar Lake has also been identified as a tidal segment with few anthropogenic disturbances. Conversely, those from Chocolate Bayou (p = 0.07) were much more diverse than expected, although not significantly greater than the 95% probability limit. The increased temporal coverage of the NTS study (monthly sampling over five calendar years) is evidenced by recording the greatest number of unique taxa, albeit at the expected level of taxonomic diversity (see Fig. 22a). While the diversity of the community recorded at Oyster Bayou with bag seines was significantly lower than expected, the nekton community recorded with otter trawls was at expected levels (p = 0.693). All of the UAA study streams fell within the expected range of taxonomic diversity, with none falling below the theoretical mean taxonomic distinctness value. Taxonomic variation was significantly higher than expected on both Bastrop (p = 0.006) and Cow Bayous' (p = 0.01; see Fig. 22a).

DISCUSSION

The initial task of the UAA studies, where this multivariate, community-based Assessment Methodology was first employed, was to determine whether any differences in the physical, chemical, or biological components of ecosystem health could be found between reference streams and the supposedly "impacted" study streams. Based on the results of those studies, no clear differences were identified between streams currently classified as either Exceptional or High, and this lack of distinction between those designations cut across all levels of trophic structure (Tolan et al., 2007). As previously stated, a limitation of the "impacted vs. reference" pair-wise comparison approach is that with only two conditions to compare, the actual differences must be very large to show any clear separation. These differences must be exceedingly large, given the natural level of variability within the physical and chemical components of ecosystem health experienced in tidally influenced systems. The purpose of this study, therefore, was to expand the number of streams analyzed with the Assessment Methodology, and to simultaneously compare data sets from varying levels of "impacted" conditions from all along the Texas coast.

Water Quality Characterizations

Surface Waters

Surface routine field parameters were only different at Cow Bayou, with the largest degree of separation appearing to be determined by the individual studies (Fig. 5). The UAA studies were clearly different from the remainder of the collections, with only Dickinson Bayou overlapping the two primary groupings identified. Despite the marked differences in surface salinity (the variable most responsible for identifying similar streams), these differences did not appear to follow any upper coast – lower coast latitudinal gradient. Highland Bayou Diversionary Canal, located on the upper coast, had average salinities higher than did tidal streams located much farther down the coast (Bastrop Bayou and Aransas River Tidal, see Table 1). More importantly, the temporal disconnect among the studies could potentially help to explain the stream groupings shown in Fig. 5. Average salinities on the UAA study streams (during the 2003 to 2004 time frame) were all approximately 3 or less, whereas many of the other study streams had average salinities two- to three-fold higher during their collections (early to mid-1990's time frame). The TCEQ-2 study on Halls and Armand Bayous' were conducted just previous to the UAA study (from 2002 to 2003), and average salinities on these systems were also < 3. Inherent differences in the climatic conditions between these decades could have had a profound effect on the ambient salinities encountered during each study, further illuminating the study-specific biases hypothesized by the present work. The TCEQ-1 study bridged a period that can be climatologically described as a "low inflow/high salinities" period, progressing into a "high inflow/low salinities" period of the moderate 1993 El Niño event (Tolan, 2007). The TCEQ-2 study also encompassed El Niño event, although the lesser 2002 event was characterized by lower inflows to a higher inflow gap during 2002 into 2003. The APA study was most unique, in that it took place during a La Niña period, resulting in one of the lowest inflow periods recorded on the Texas coast (Tolan, 2007). Coast-wide salinities during the UAA studies were generally moderate to low, although this period (2003 to 2004) was characterized as a normal weather period, neither La Niña nor El Niño.

While the ANOSIM procedure did find a significant difference in surface water quality (Cow Bayou was identified as being different from the remainder of streams, see Fig. 5), the low value of this test (Global R = 0.285) is indicative of a high degree of variability among the stations on each stream. This variability is shown in Fig. 4. Despite dramatic differences in the temporal coverage amongst the studies, each stream displays considerable internal variability from sampling event to sampling event.

Both the spatial and temporal coverage's of surface water chemical properties were far lower than those of the routine field parameters, and the general pattern of the study streams in the chemistry-based MDS space is markedly different (Fig. 7). Surface waters in Cow Bayou no longer feel outside the main grouping of streams, but rather had very similar nutrient loads, suspended solids, and primary production as did most all other tidal systems. Tidal streams generally considered as "impaired" were the systems that were identified by this analysis as being most unique (Fig. 8). Excess nutrient loads within Texas City Pump Canal, Highland Bayou Diversionary Canal, and Dickinson Bayou lead to these systems generally falling outside the main MDS grouping. Lost River was also identified as being unique, but it was an opposite situation of lowest nutrient loads, as evidence by the low average values of ammonia, phosphates, and total organic carbon that was seen in this system. The uniqueness of Lost River in this MDS configuration is also evidenced by the dramatically lower levels of variability in these same readings.

Bottom Waters

Compared to the surface water collections, an even lower Global R value characterized the ANOSIM test of bottom water routine field parameters. While this result reinforces the high degree of variability seen among individual sampling events, as well as among each of the study streams, there were still highly significant comparisons of bottom water properties that mirrored the results of the surface water collections. Cow Bayou was again identified as the most unique tidal stream, and like the surface collections, it was the salinity gradient found on this stream that was most influential in this determination. Temporal bias was also seen in the bottom water measurements, with the UAA studies identified as being different form the TCEQ and the APA studies. Oyster and Halls Bayous' grouped with the UAA studies, but again it was the lower salinity values on these two streams that helped to link these two streams to the low salinity UAA group.

Most importantly, latitudinal differences in the location of major tidal systems along the coast do not appear to be replicated by their placement within the MDS spaces, with respect to either physical or chemical properties (Figs. 5, 8, & 15). In each case, major groupings of tidal streams were mixtures of systems physically located all along the coast. Only the chemical properties could readily identify "impacted" systems, and the correlation between the surface and bottom measurements was quite high.

Nekton Assemblages

Based on the total nekton collections shown in Fig. 10, salinity appears to play an overarching role in structuring the nektonic communities recorded by the bag seine collections. Even after reducing the collections to a common season amongst the various studies (Fig. 12), salinity still appears to be the parameter most responsible for structuring tidal stream communities. Yet, even across dramatic salinity differences, the same handful of taxa dominated the collections from every study stream under consideration. The highly euryhaline families of Engraulidae, Penaeidae, Paleomonidae, Atherinidae, Portunidae, and Clupeidae numerically dominated every stream, and these same families are common to estuaries all along the Gulf of Mexico and Atlantic coasts (Rozas and Hackney, 1984; Peterson and Ross, 1991; Baltz et al., 1993; Ogburn-Matthews and Allen, 1993; Rozas and Minello, 2007).

While the role of salinity was determined to be important in determining the spatial placement of streams in the MDS configurations for each of the physical, chemical, and biological components of ecosystem health, the climate-induced bias amongst the studies seen in the physical and chemical measurements was not replicated with the biological collections. Here, the inherent biases among the studies appear to be in the form of sampling methodologies. Even across climate-related decadal differences, the very same taxa dominate the nekton on each stream under consideration. Missing from Fig. 12 is any connection between the "impaired" water quality streams shown in Fig. 8 to the biological communities recorded with the bag seines. For example, communities recorded at Texas City Pump Canal were similar to those collected from the more pristine locations on the upper coast (Cedar Lake Creek, Oyster Bayou, and Lost River), as well as those from the middle and lower coast (Garcitas Creek, and the Aransas River Tidal).

Salinity appeared to have a lesser role in structuring the communities recorded with the otter trawls, and this is a reflection of the different taxa recorded by this gear. While the dominance of the euryhaline families of Penaeidae, Engraulidae, and Clupeidae were still evident with the trawls, members of the families Sciaenidae (marine nekton) and Ictaluridae (freshwater nekton) made up the majority of the remainder of this catch. Both spot and Atlantic croaker (sciaenids) are noted for their abilities to inhabit brackish water conditions (Patillo, et al., 1997), and the blue catfish (ictalurid) is a freshwater species common in both fresh and brackish waters. Like the community structure seen with the bag seines, otter trawls did not appear to reflect any consistent connection of the "impaired" conditions, as revealed by the chemical constituents, and those seen with the biological components. Over-representations of particular taxa (e.g., white shrimp, Atlantic croaker, and spot in the TCEQ studies) because of sampling methodologies biases appears to play a larger role in the structuring of the otter trawl communities within the MDS space. Although sampling biases among the studies was still quite evident, the same general communities were recorded from each tidal system, regardless of any level of impairment.

Taxonomic Information

Measures of taxonomic diversity (both Delta$^+$ and Lambda$^+$) reinforced the methodological biases found among the studies, yet each failed to show any strong connection between any of the supposedly "impaired" water-bodies, as measured by more traditional physical and chemical methods, to their biological components. In each gear, the lowest levels of taxonomic diversity were found on the least disturbed streams, or streams that had been previously used as reference conditions. These results are counter-intuitive to the suggestions put forth by Clarke and Warwick (2001), in that "impairments" should be connected with a loss of both the normal wide spread of higher taxa (reduced Delta$^+$ value), and the higher taxa lost are those with a more simple subsidiary tree structure, represented by only one or two species, genera or families, leaving a more balanced classification tree (reduced Lambda$^+$ value).

CONCLUSIONS

The many different processes and effects of coastal eutrophication are well known and documented (Cloern, 2001; Conley et al., 2002; Ronnberg and Bonsdorff, 2004). Numerous examples of watershed degradation leading to severe biological consequences are more and more common worldwide (Jones, et al., 2000; Anderson et al., 2006; Xu et al., 2006; Padmini and Geetha, 2007). Many of the preceding examples document clearly many of the debilitating effects that excessive anthropogenic inputs can have on overall ecological health. In the present analysis, the absence of clear connections between degraded water-bodies and their biotic communities should not automatically be viewed as a constraint brought about by the techniques of this new methodology, but rather could be thought as *de facto* verification that severely impaired water-bodies are not that common of an occurrence along the Texas coast.

The assessment methodology used for this study was designed to capture community-level information on the richness of the tidal stream assemblages, both in terms of the number of species present (as well as their numeric abundance) and their states of phylogenetic relatedness. These methods were applied to the communities recorded by disparate gears, sampling very different parts of the overall tidal stream habitat. Both the bag seines (side of the stream, near-surface collections; young-of-the-year and juvenile stages) and otter trawls (middle of the stream, near-bottom collections; juvenile and sub-adult stages) generally recorded very similar, and very consistent communities, regardless of the “impairments” associated with each stream. All communities were dominated by a few taxa that each display tremendous euryhaline / physiological abilities (Gunter, 1961). These abilities allow these taxa to adapt to a wide variety of salinity conditions. And it is because of these physiological abilities, few tidal stream organisms can truly be described as “sensitive”. As such, the end result of the Assessment Methodology, as shown in Fig. 2, currently lacks the critical Index Development step. This step is predicated on ‘candidate taxa’ that are sensitive to changes in the sometimes dramatic changes in the chemical or physical conditions found in tidally influenced ecosystems. As the mine canary can warn of the presence of a poisonous gas in a coal mine, the abundance or even presence of a few sensitive estuarine fishes could be used to document the early effects of water-body degradation (Clark et al., 1998). The downside to this approach is that management recommendations at the ecosystem-level could potentially be built upon the utmost weakest of foundations.

Isolating the effects of the abiotic drivers on long-lived species, such as estuarine fishes, requires years of monitoring that span the range of natural conditions, and too often, data sufficient to detect the effects are not obtained until it is too late and the population has suffered measurable decline (Walters & Collie 1988). One approach in the evaluation many fish-based metrics is to narrow the assessment time frame to some index period (usually during the 'high stress summer period', see Deegan et al. 1997; TCEQ 2000). Intuitively, the inverse relationship between temperature and dissolved oxygen should be manifested as a large stressor on the monitored organisms, resulting in fewer species, fewer individuals, and lower biomass in areas of additional high anthropogenic stressors. Too much focus on a specific stressor alone can lead to misleading predictions of responses because of inadequate information on how other factors affect the response of the population (Rose 2000). In the present study, summer collections had a great degree of salinity-mediated variability in their community compositions, and would have required substantially more sampling effort to overcome their low statistical power. Expanding the temporal scale of the current analysis technique to more uniform datasets that encompass a greater seasonal resolution may lead to more illuminating results, at a truly coast-wide spatial scale.

LITERATURE CITED

Andersen, J.H., L. Schluter, G. Aertebjerg. 2006. Coastal eutrophication: recent developments in definitions and implications for monitoring strategies. Joiurnal of Plankton Research. 28:621-628.

APA (Alan Plummer Associates, Inc.). 1997. Determination of Aquatic Life Use Classification Nueces River Tidal. Final Report. Submitted to the City of Corpus Christi. 88 pp.

Baltz, D.M., C. Rakocinski, and J.W. Fleeger. 1993. Microhabitat use by marsh-edge fishes in a Louisiana estuary. Env. Biol. Fish. 36:109-126.

Clark, T., K. Clark, S. Paterson, D. MacKay, and R.J. Norstrom. 1998. Wildlife monitoring, modeling, and fugacity. Environmental Science and Technology 22:120-127.

Clarke, K.R., and R.M. Warwick. 2001. Change in marine communities: an approach to statistical analysis and interpretation, 2nd Edition. PRIMER-E: Plymouth, United Kingdom.

Cloern, J. 2001. Our evolving conceptual model of the coastal eutrophication problem. Marine Ecology Progress Series. 210:223–253.

Conley, D. J., Markager, S., Andersen, J. et al. 2002. Coastal eutrophication and the Danish National Aquatic Monitoring and Assessment Program. Estuaries. 25:706–719.

Contreras, C., J. Nelson, and J. Tolan. 2005. Proposed Methodology for Determining Site-Specific Uses and Criteria within Tidally Influenced Portions of the River Basin and Coastal Basin Waters of Texas. Prepared for the Texas Commission on Environmental Quality, Contract 582-2-48657. 44 pp.

Deegan; L.A., Finn; J.T., Ayvazian; S.G., Ryder-Kieffer; C.A., & Buonaccorsi, J. 1997. Development and validation of an estuarine biotic integrity index. *Estuaries* 20:601-617.

Guillen, G.J. 1996. Development of a rapid bioassessment method and index of biotic intergrity for tidal streams and bayous located along the Northwest Gulf of Mexico. Texas Natural Resource Conservation Commission. 257 pp.

Gunter, G. 1961. Some relation of estuarine organisms to salinity. Limn. and

Ocean. 6:182-190.

Jones, G.B., P. Mercurioa, and F. Oliviera. 2000. Zinc in fish, crabs, oysters, and mangrove flora and fauna from Cleveland Bay. Marine Pollution Bulletin 41:345-352.

Ogburn-Matthews, M.V., and D.M. Allen. 1993. Interactions among some dominant estuarine nekton species. Estuaries 16:840-850.

Padmini, E., and B.V. Geetha. 2007. A comparative seasonal pollution assessment study on Ennore Estuary with respect to metal accumulation in the grey mullet, *Mugil cephalus.* Oceanological and Hydrobiological Studies 36: 91-103.

Pattillo, M.E., T.E. Czapla, D.M. Nelson and M.E. Monaco. 1997. Distribution and abundance of fishes and invertebrates in Gulf of Mexico estuaries, Volume II: Species life history summaries. ELMR Rep. No. 11. NOAA/NOS Strategic Environmental Assessments Division, Silver Spring, MD. 377 pp.

Peterson, M.S., and S.T. Ross. 1991. Dynamics of littoral fishes and decapods along a coastal river-estuarine gradient. Estuarine, Coastal and Shelf Science 33:467-483.

Ronnberg, C., and E. Bonsdorff. 2004. Baltic Sea eutrophication: area specific ecological consequences. Hydrobiologia 514:227–241.

Rose, K.A. 2000. Why are quantitative relationships between environmental quality and populations so elusive? Ecological Applications 10(2):367-385.

Rozas, L.P., and C.T. Hackney. 1984. Use of oligohaline marshes by fishes and macrocrustaceans in North Carolina. Estuaries 7:213-224.

Rozas, L.P., T.J. Minello. 2007. Restoring coastal habitat using marsh terracing: the effect of cell size on nekton use. Wetlands 27:595-609.

TCEQ. 2000 Texas Surface Water Quality Standards. §§307.1 - 107.10. Adopted by the Commission: July 26, 2000. Effective August 17, 2000 as a State rule.

TCEQ. 2008. Draft Texas 303(d) List (19 March 2008). Accessed on 10JUN08 from the Texas Commission on Environmental Quality website: http://www.tceq.state.tx.us/assets/public/compliance/monops/water/08twqi/2008_303d.pdf

Tolan, J.M. 2007. El Niño-Southern Oscillation impacts translated to the watershed scale: Estuarine salinity patterns along the Texas Gulf Coast, 1982-2004. Estuarine, Coastal and Shelf Science. 72:247-260.

Tolan, J., J. Nelson, N. Kuhn, and D. German. 2007. Final Report for Determining Site-Specific Uses and Criteria within the Tidally Influenced Portions of Tres Palacios River and Garcitas Creek. Prepared for Texas Commission on Environmental Quality, Contract 582-2-48657. 250 pp.

Walters, C.J., and J.S. Collie. 1988. Is research on environmental factors useful to fisheries management? Canadian Journal of Fisheries and Aquatic Sciences 45:1848-1854.

Xu, F.-L., J.-Y. Hao, S. Tao, R.W. Dawson, K.C. Lam, Y.D. Chen. 2006. Restoration of marine coastal ecosystem health as a new goal for integrated catchment management in Tolo Harbor, Hong Kong, China. Environmental Management. 37:540-552.

Table 1. Surface-water Field parameters by tidal stream. Temperature (Temp.) in ^{o}C, Dissolved Oxygen (D.O.) in mg/L, Specific Conductance (Specific Cond.) in µmhos/cm, Salinity in PSU, Secchi Depth in m. Data are means, standard deviations in parenthesis. See text for individual stream sample sizes.

Tidal Stream	Temp.	(SD)	pH	(SD)	D.O.	(SD)	Specific Conduct.	(SD)	Salinity	(SD)	Secchi Depth	(SD)
Tres Palacios	25.60	(4.3)	7.70	(0.6)	6.75	(1.5)	5410.97	(6439.5)	3.08	(3.8)	0.30	(0.2)
Carancahua	25.83	(4.5)	7.71	(0.6)	6.18	(1.7)	4080.94	(5405.5)	2.29	(3.2)	0.24	(0.1)
Garcitas	28.16	(5.1)	7.52	(0.5)	6.04	(1.2)	2522.25	(4758.4)	1.42	(2.8)	0.26	(0.2)
Cow Bayou	25.52	(5.0)	6.57	(0.5)	5.05	(1.6)	1953.46	(3397.3)	1.08	(1.9)	0.48	(0.2)
Lost River	26.14	(4.2)	7.67	(0.3)	7.27	(1.5)	628.36	(892.2)	0.34	(0.6)	0.36	(0.1)
Nueces	29.83	(1.0)	8.25	(0.3)	7.30	(3.1)	12350.00	(9810.1)	6.62	(5.5)	0.35	(0.1)
Mission	31.13	(1.1)	7.90	(0.1)	7.27	(1.3)	13051.67	(10486.9)	6.73	(5.6)	0.55	(0.1)
Aransas	31.18	(1.3)	8.20	(0.2)	9.02	(2.1)	22716.67	(8694.9)	12.15	(5.0)	0.40	(0.1)
Bastrop	29.22	(1.5)	7.72	(0.3)	6.13	(1.6)	18181.67	(18138.4)	10.32	(11.0)	0.52	(0.2)
Chocolate	29.85	(1.5)	7.80	(0.2)	7.47	(1.9)	11792.67	(10805.3)	6.20	(5.9)	0.48	(0.1)
Armand	29.41	(1.5)	8.12	(0.6)	6.16	(2.4)	4411.56	(6059.0)	2.50	(3.5)	0.45	(0.2)
Halls	29.80	(1.4)	7.70	(0.4)	5.74	(2.1)	4810.50	(7080.5)	2.76	(4.2)	0.48	(0.3)
Oyster	26.91	(4.4)	7.26	(0.4)	6.22	(1.3)	6036.46	(7647.2)	3.47	(4.6)	0.27	(0.1)
Dickinson	25.51	(4.7)	7.80	(0.3)	6.78	(1.6)	7443.64	(7920.6)	4.30	(4.8)	0.37	(0.2)
TCPC	24.14	(4.0)	7.84	(0.4)	7.17	(3.5)	12570.91	(7247.8)	7.35	(4.4)	0.33	(0.1)
HBDC	26.06	(5.4)	8.03	(0.4)	6.57	(1.9)	24300.00	(13670.7)	14.81	(8.7)	0.52	(0.1)
Cedar Lake	24.65	(3.5)	7.71	(0.3)	5.39	(1.1)	10979.36	(15294.5)	6.65	(9.5)	0.33	(0.1)

Table 2. Surface-water Conventional parameters by tidal stream. Ammonia, Orthophosphate (Orthophos.), Total Phosphorus (Total Phos.), Total Suspended Solids (TSS), and Total Organic Carbon (TOC) in mg/L. Chlorophyll a (Chl_a) in µg/L. Data are means, standard deviations in parenthesis. See text for individual stream sample sizes.

Tidal Stream	Ammonia	(SD)	Ortho-Phos.	(SD)	Total-Phos.	(SD)	Chl a	(SD)	TSS	(SD)	TOC	(SD)
Tres Palacios	0.07	(0.04)	0.20	(0.17)	0.28	(0.18)	15.68	(19.60)	127.94	(221.79)	6.20	(1.57)
Carancahua	0.06	(0.02)	0.20	(0.11)	0.29	(0.17)	13.77	(18.29)	42.97	(31.63)	7.77	(1.54)
Garcitas	0.07	(0.03)	0.14	(0.10)	0.19	(0.08)	9.37	(10.79)	38.53	(60.73)	10.31	(4.37)
Cow Bayou	0.07	(0.04)	0.09	(0.08)	0.10	(0.05)	8.48	(10.67)	15.63	(11.95)	11.25	(4.18)
Lost River	0.05	(0.01)	0.07	(0.02)	0.14	(0.04)	11.67	(10.87)	35.77	(16.72)	6.37	(0.55)
Armand	0.07	(0.04)	0.26	(0.15)	0.39	(0.22)	34.92	(41.61)	38.33	(22.36)	6.87	(1.13)
Halls	0.07	(0.02)	0.11	(0.05)	0.17	(0.06)	14.54	(8.50)	28.06	(18.27)	8.53	(2.55)
Oyster	0.08	(0.06)	0.12	(0.12)	0.22	(0.26)	13.67	(14.80)	54.74	(51.00)	11.94	(7.71)
Dickinson	0.43	(0.84)	0.16	(0.06)	0.22	(0.07)	17.59	(12.92)	25.95	(16.03)	7.57	(6.66)
TCPC	0.24	(0.53)	0.09	(0.04)	0.16	(0.06)	22.47	(19.97)	17.33	(4.80)	1.78	(3.83)
HBDC	1.83	(1.94)	2.10	(2.26)	3.16	(3.44)	108.48	(59.18)	37.00	(19.35)	4.46	(7.34)
Cedar Lake	0.03	(0.01)	0.09	(0.04)	0.15	(0.03)	7.17	(5.08)	22.25	(11.22)	9.08	(6.44)

Table 3. Summary of bag seine sampling efforts by study. See text for descriptions of 6 most abundant taxa.

	TCEQ-1	TCEQ-2	APA	UAA
Number of Tidal Streams	5	2	5	5
Number of Seasons Sampled	4	2	1	3
Total Catch	202,441	23,329	19,766	152,664
Total Number of Taxa	93	73	76	105
Total of 6 Most Abundant Taxa	173,798	16,779	18,971	138,695
Percentage of Total Catch	85.9	71.9	96.0	90.8

Table 4. Similarity Percentage (SIMPER) results for summer bag seine collections summer collections, by study. Percent contribution to the Average Similarity are listed for each taxa. Empty cells represents contributions < 2 % to the Average Similarity. Stream designations: Oyster Bayou (OB), Dickinson Bayou (DB), Texas City Pump Canal (TCPC), Highland Bayou Diversionary Canal (HBDC), Cedar Lake Creek (CLk), Armand Bayou (AB), Halls Bayou (HB), Nueces River Tidal (NR), Mission River Tidal (MR), Aransas River Tidal (AR), Bastrop Bayou (BB), Chocolate Bayou (ChB), Tres Palacios Tidal (TP), West Carancahua (WC), Garcitas Creek (GC), Lost River (LR), and Cow Bayou (CB).

	Study																
	TCEQ-1					TCEQ-2		APA					UAA				
Species	OB	DB	TCPC	HBDC	CLk	AB	HB	NR	MR	AR	BB	ChB	TP	WC	GC	LR	CB
Bay anchovy	26.1	28.1			6.5	14.5	4.6	26.8	27.0	39.7	12.5	4.4	31.2	42.3	28.7	33.1	30.6
Western mosquitofish	5.0		4.4		8.5	21.7	11.0		3.4			2.8	13.1	11.8	3.0	3.9	
Gulf menhaden	2.8		3.9								11.8	10.8	12.1	9.7	5.7	25.5	
Sailfin molly												2.8		4.2	4.9		
White shrimp	11.2	5.1	22.4	30.8	33.4			36.0	28.3	21.8	54.7	66.7		4.0	6.4		
Grass shrimp	25.4		24.2	19.0	22.1	20.3	25.7	8.9	21.4	21.4				3.7		6.8	
Silverside spp.	4.1	41.0	8.1	14.5	10.8	34.5		7.3	5.0	3.9			9.6	3.6	3.5		3.2
Hogchoker													5.6				
Blue crab	14.1	13.3	7.3	8.5	9.7							3.2	5.1		11.0	14.3	12.3
Blue catfish													4.8	2.3	2.8		
Brown shrimp			9.9										4.3	3.4			2.1
Striped mullet											3.1		3.4	3.7	10.2		
Sand seatrout	2.0													2.9			
Pinfish				12.7							3.1				3.8		
Hogchoker															3.6	7.7	
Gulf killifish			3.1	3.3			10.8										
Bay whiff															2.2		
Mojarra spp.											2.4				2.1		
Bluegill																	16.3

Table 4 (cont.)

	Study																
	TCEQ-1					TCEQ-2		APA					UAA				
	OB	DB	TCPC	HBDC	CLk	AB	HB	NR	MR	AR	BB	ChB	TP	WC	GC	LR	CB
Largemouth bass																	13.9
Redear sunfish																	8.4
White mullet								3.6									1.9
Spotted sunfish							23.5										1.4
Spot		3.2						2.4									
Spotted seatrout							8.7	2.4	3.2	4.7							
Family Syngnathidae									3.0								
Atlantic leatherjacket											3.2						
Spotted bass							4.5										
Clown goby							3.5										
Fat sleeper			8.9														
Sheepshead minnow				2.3													
Average Similarity	36.9	35.6	73.0	58.0	31.1	35.7	46.8	37.3	36.7	47.5	44.9	36.1	32.1	28.6	23.7	31.2	24.5

Table 5. Bottom-water Field parameters by tidal stream. Temperature (Temp.) in ^{o}C, Dissolved Oxygen (D.O.) in mg/L, Specific Conductance (Specific Cond.) in µmhos/cm, Salinity in PSU, Secchi Depth in m. Data are means, standard deviations in parenthesis. See text for individual stream sample sizes.

.

Tidal Stream	Temp	(SD)	pH	(SD)	D.O.	(SD)	Specific Cond.	(SD)	Salinity	(SD)
Tres Palacios	26.19	(4.4)	7.54	(0.4)	4.37	(2.0)	4451.33	(6451.8)	2.48	(3.7)
Carancahua	25.28	(4.6)	7.33	(0.5)	3.58	(2.7)	3928.21	(4516.4)	2.17	(2.6)
Garcitas	25.43	(4.4)	7.34	(0.6)	4.50	(1.9)	6298.89	(7416.9)	3.65	(4.4)
Cow Bayou	25.42	(4.6)	6.64	(0.4)	4.31	(1.4)	3212.74	(5048.9)	1.80	(3.0)
Lost River	25.86	(4.1)	7.56	(0.3)	5.93	(2.0)	682.40	(1108.9)	0.36	(0.6)
Nueces-APA	29.83	(1.0)	8.25	(0.3)	3.95	(2.5)	15433.33	(11130.6)	8.40	(6.4)
Mission	31.13	(1.1)	7.90	(0.1)	4.27	(3.3)	15766.67	(9354.1)	8.20	(5.1)
Aransas	31.18	(1.3)	8.20	(0.2)	7.35	(3.3)	24700.00	(8063.5)	13.48	(4.7)
Bastrop	29.22	(1.5)	7.72	(0.3)	3.03	(2.0)	20513.33	(19033.2)	11.83	(11.9)
Chocolate	29.85	(1.5)	7.80	(0.2)	2.02	(2.3)	15913.33	(11186.6)	8.43	(6.3)
Armand	28.80	(3.0)	8.60	(0.4)	7.95	(1.5)	6238.50	(6592.4)	3.50	(3.8)
Halls	29.03	(2.5)	7.48	(0.3)	5.00	(1.5)	4063.00	(7093.2)	2.34	(4.2)
Oyster	23.95	(6.3)	7.19	(0.4)	5.82	(2.0)	6985.85	(8432.1)	4.06	(5.1)
Dickinson	25.64	(5.2)	7.85	(0.3)	4.28	(2.9)	10853.00	(10365.3)	6.38	(6.4)
HBDC	26.90	(5.0)	8.03	(0.4)	3.39	(2.2)	28091.67	(11387.0)	17.19	(7.4)
CedarLk	24.94	(4.6)	7.73	(0.4)	5.11	(1.0)	8812.00	(15172.1)	5.34	(9.4)
Nueces-NTS	25.16	(5.3)	8.22	(0.4)	6.48	(3.0)	17019.52	(17679.6)	10.56	(11.6)

Table 6. Summary of otter trawl sampling efforts by study. See text for descriptions of 6 most abundant taxa.

	TCEQ-1	TCEQ-2	APA	NTS	UAA
Number of Tidal Streams	4	2	5	1	5
Number of Seasons Sampled	4	2	1	4	3
Total Catch	55,326	3,384	24,359	34,186	150,324
Number of Taxa	72	73	75	80	76
Total of 6 Most Abundant Taxa	37,238	2,577	19,352	21,947	144,576
Percentage	67.3	76.2	77.8	64.2	96.2

Table 7. Similarity Percentage (SIMPER) results for summer otter trawl collections, by study. Percent contribution to the Average Similarity are listed for each taxa. Empty cells represents contributions < 2 % to the Average Similarity. Stream designations: Oyster Bayou (OB), Dickinson Bayou (DB), Texas City Pump Canal (TCPC), Highland Bayou Diversionary Canal (HBDC), Cedar Lake Creek (CLk), Armand Bayou (AB), Halls Bayou (HB), Nueces River Tidal (NR), Mission River Tidal (MR), Aransas River Tidal (AR), Bastrop Bayou (BB), Chocolate Bayou (ChB), Tres Palacios Tidal (TP), West Carancahua (WC), Garcitas Creek (GC), Lost River (LR), and Cow Bayou (CB).

	Study																
	TCEQ-1				TCEQ-2		APA					NTS	UAA				
Species	OB	DB	HBDC	CLk	AB[1]	HB	NR	MR	AR	BB	ChB	NR	TP	WC	GC	LR	CB
White shrimp	19.2	16.3		29.6		76.8	21.3	44.9	52.2	33.0	48.8	20.1					5.6
Blue catfish	12.9	2.8					7.3					17.8	9.2	8.5		25.5	14.9
Atlantic croaker	19.7		5.8						18.9	7.4	4.5	14.9				6.9	3.4
Gulf menhaden	2.0	6.2		3.5				10.2				10.1	24.1	19.4	15.9	8.9	3.1
Bay anchovy		22.6	5.7	14.7		23.2	12.9	31.9	18.8	30.5	15.3	8.2	59.0	66.3	78.2	32.5	40.2
Hardhead catfish			5.7									6.2					
Brown shrimp	4.0			3.3								5.6					3.3
Blue crab	22.4	9.5		6.1							4.5	3.7				4.0	
Spot		22.4	5.8	16.8			26.3					3.3					6.9
Silver perch							21.6					2.7					
Naked goby							6.8										
Common carp								13.0									
Sand seatrout	9.9	12.5	71.1	12.2					2.2	9.0	15.3						4.8
Pinfish				3.9						7.3							
Silver perch										4.2							
Bay whiff											4.5						
Channel catfish																7.7	5.1
Hogchoker																3.6	

Table 7 (cont.)

							Study										
	TCEQ-1				TCEQ-1		APA						NTS			UAA	
Species	OB	DB	HBDC	CLk	AB*	HB	NR	MR	AR	BB	ChB	NR	TP	WC	GC	LR	CB
Spotted gar																2.5	
Bluegill																	2.8
Average Similarity	41.0	26.4	9.9	49.5		19.6	10.4	10.3	31.9	13.2	1.8	25.0	36.4	44.1	44.5	33.2	26.5

* Insufficient sample size to perform SIMPER analysis.

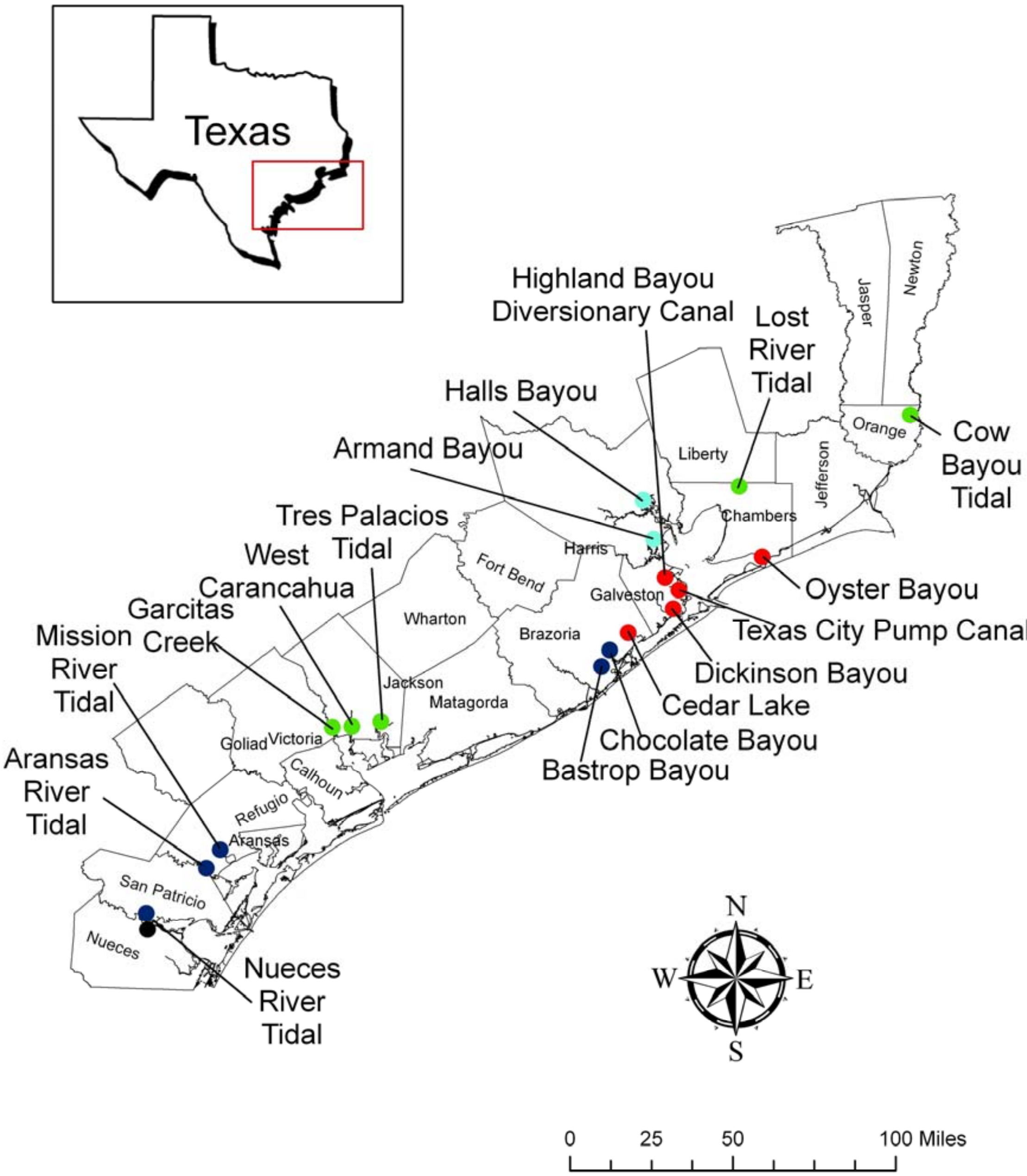


Figure 1. Map of tidal stream locations used for the Coast-wide Assessment Methodology, color-coded by study: red = TCEQ-1, light blue = TCEQ-2, dark blue = APA, green = UAA, black = NTS.

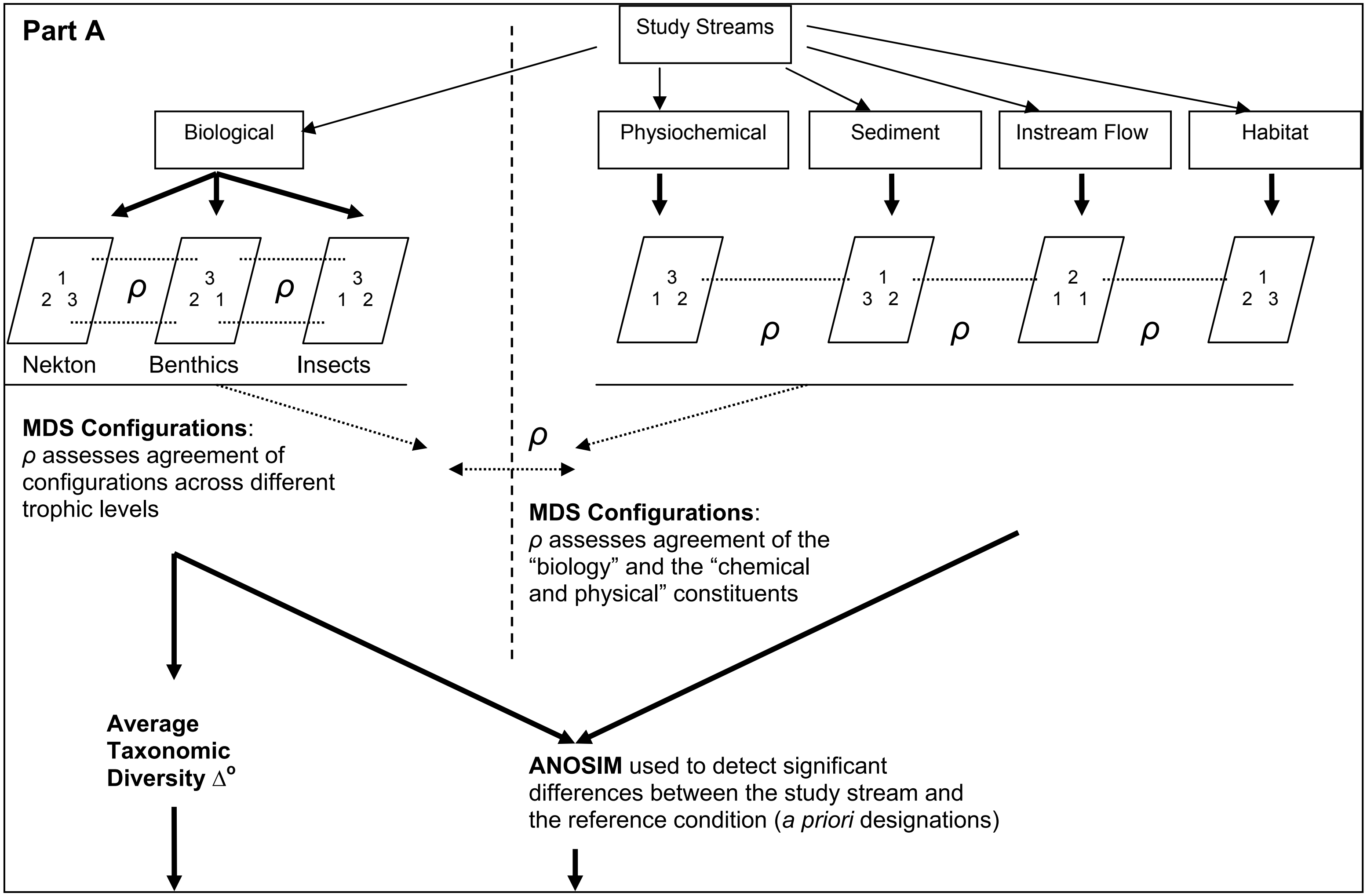


Figure 2. The process for assessing ecosystem health and determining biocriteria in tidally influenced streams.

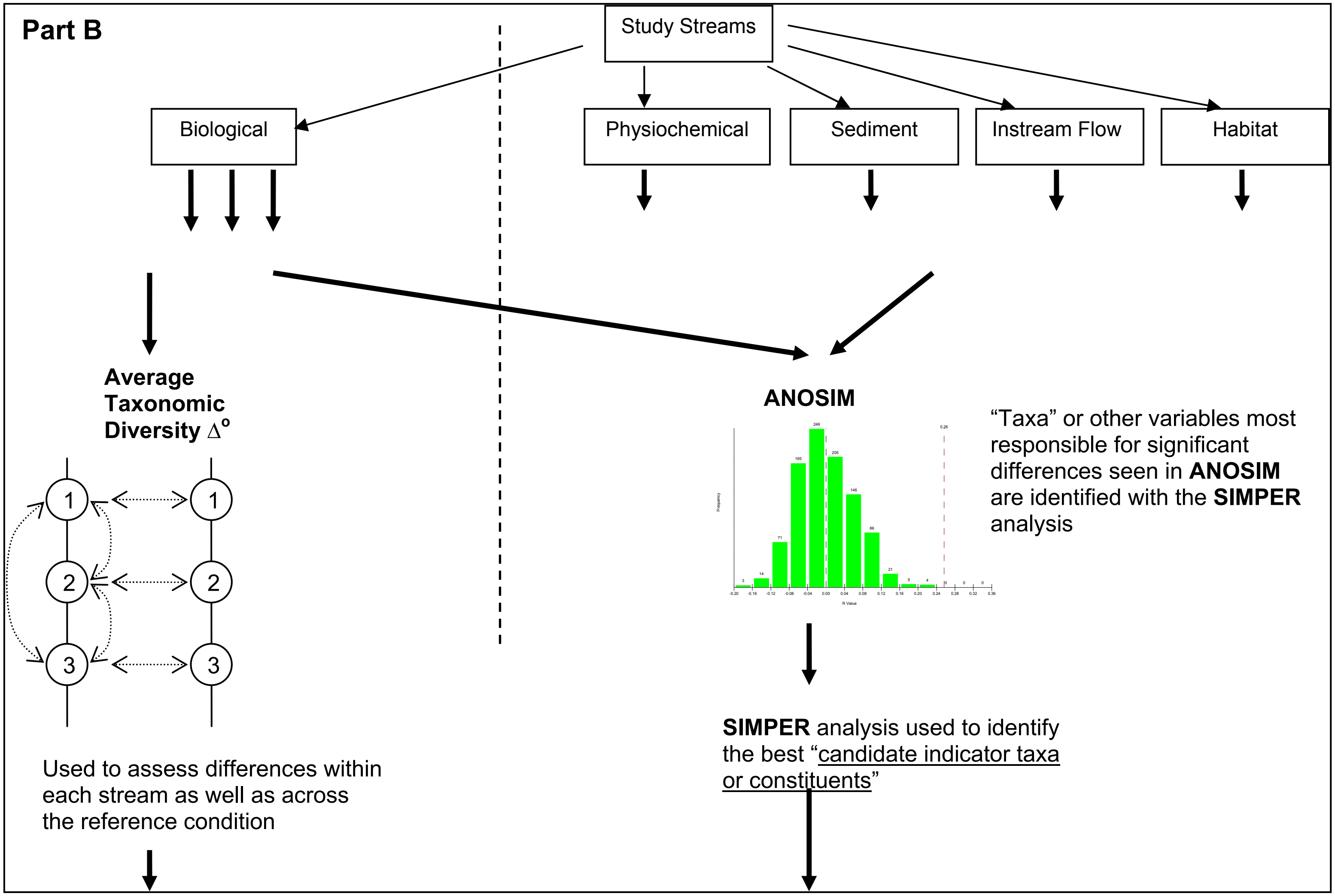


Figure 2. The process for assessing ecosystem health and determining biocriteria in tidal streams (continued).

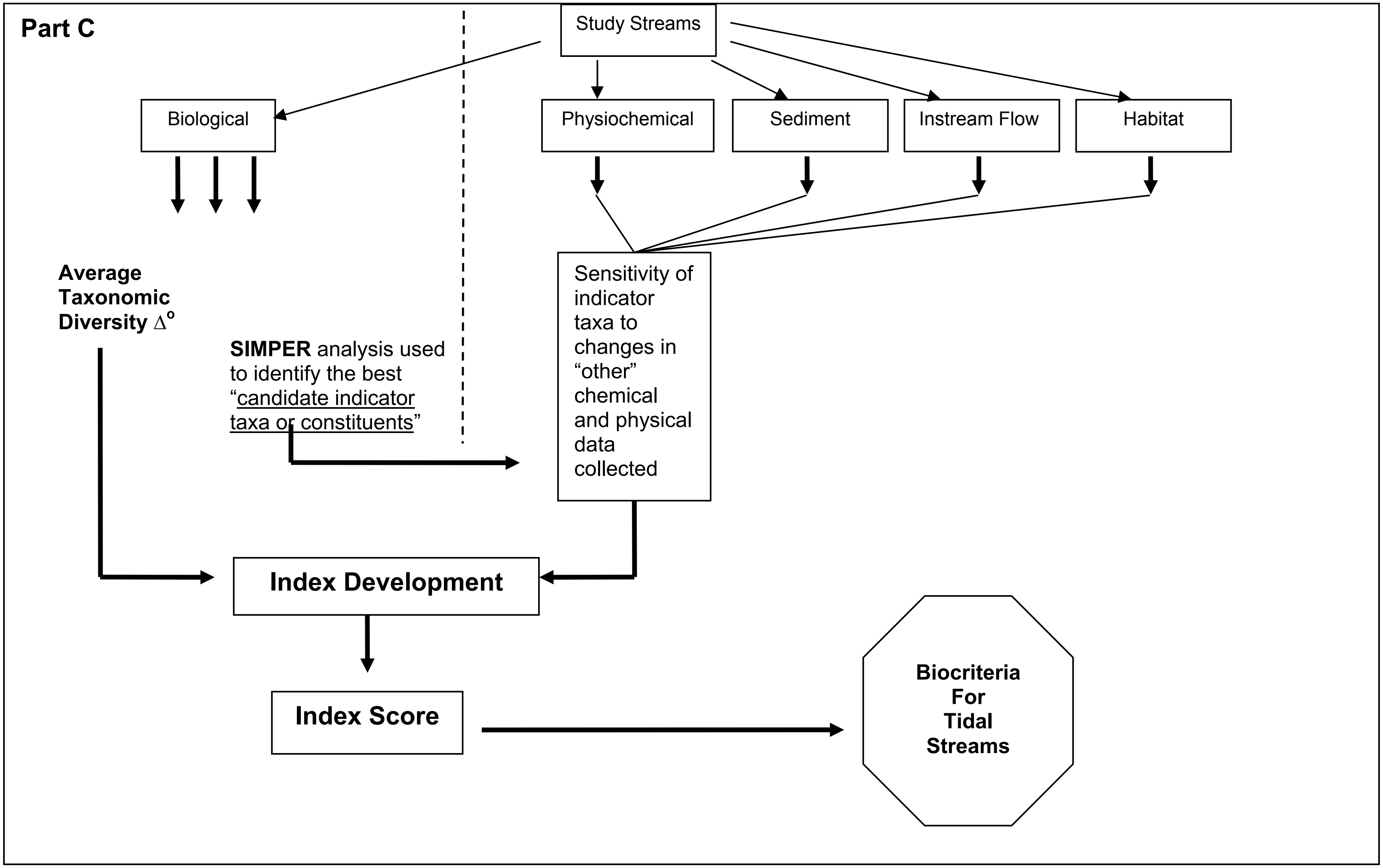


Figure 2. The process for assessing ecosystem health and determining biocriteria in tidal streams (continued)..

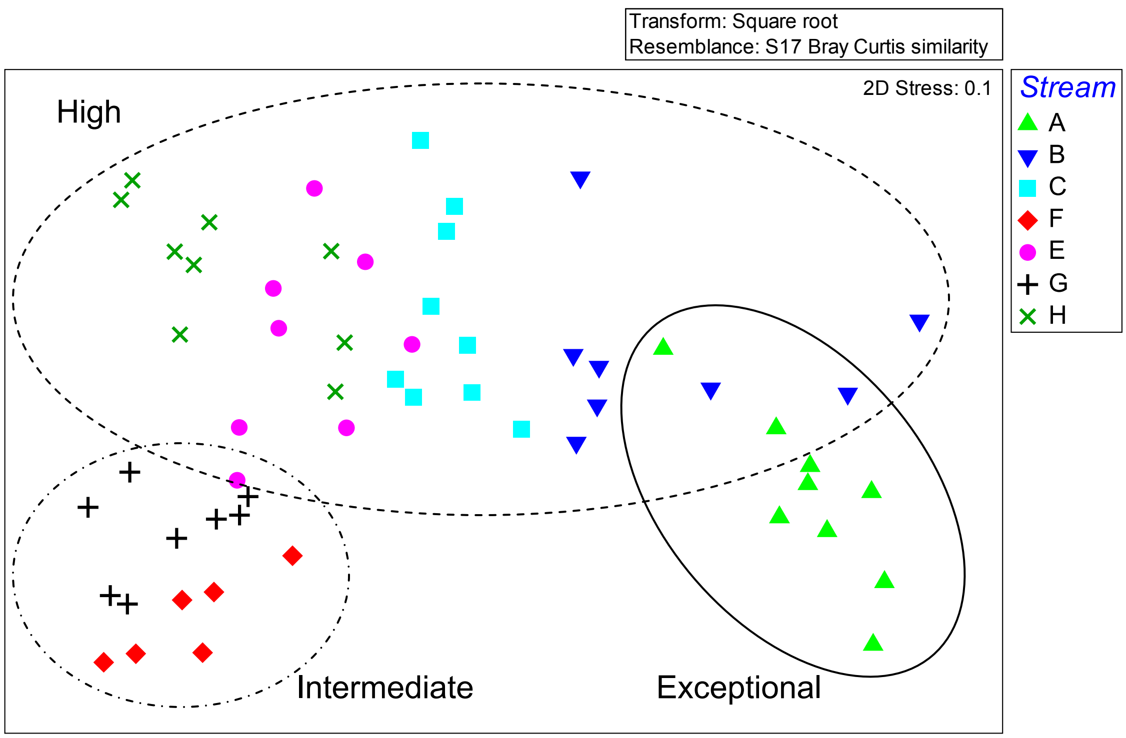


Figure 3. Hypothetical MDS ordination of biological collections from seven tidally influenced coastal stream. Stream A is designated as the Reference Stream. Aquatic Life Use designations as follows: Stream A = Exceptional (enclosed in solid line ellipse); Streams B, C, E, and H = High (enclosed in dashed line ellipse); and Streams F and G = Intermediate (enclosed in dash-dotted line ellipse).

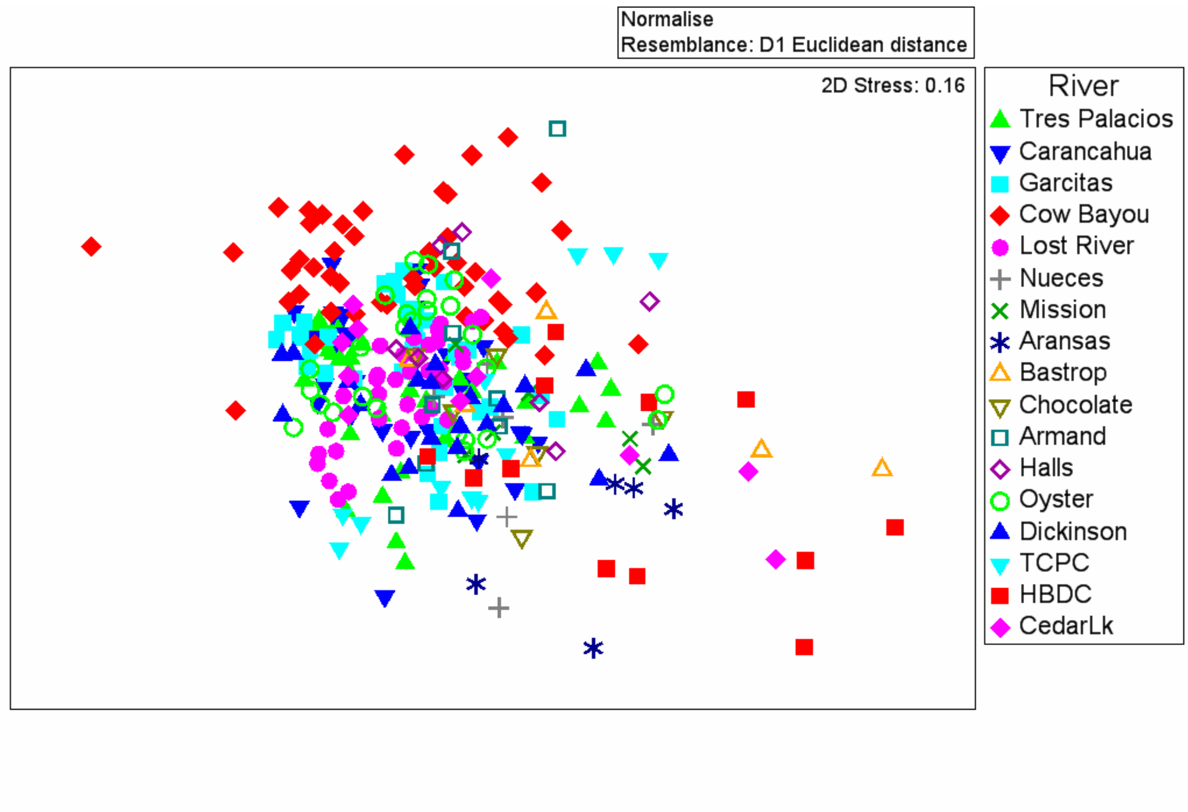


Figure 4. Multidimensional scaling ordination of the tidal stream locations based on surface measurements of routine Field parameters.

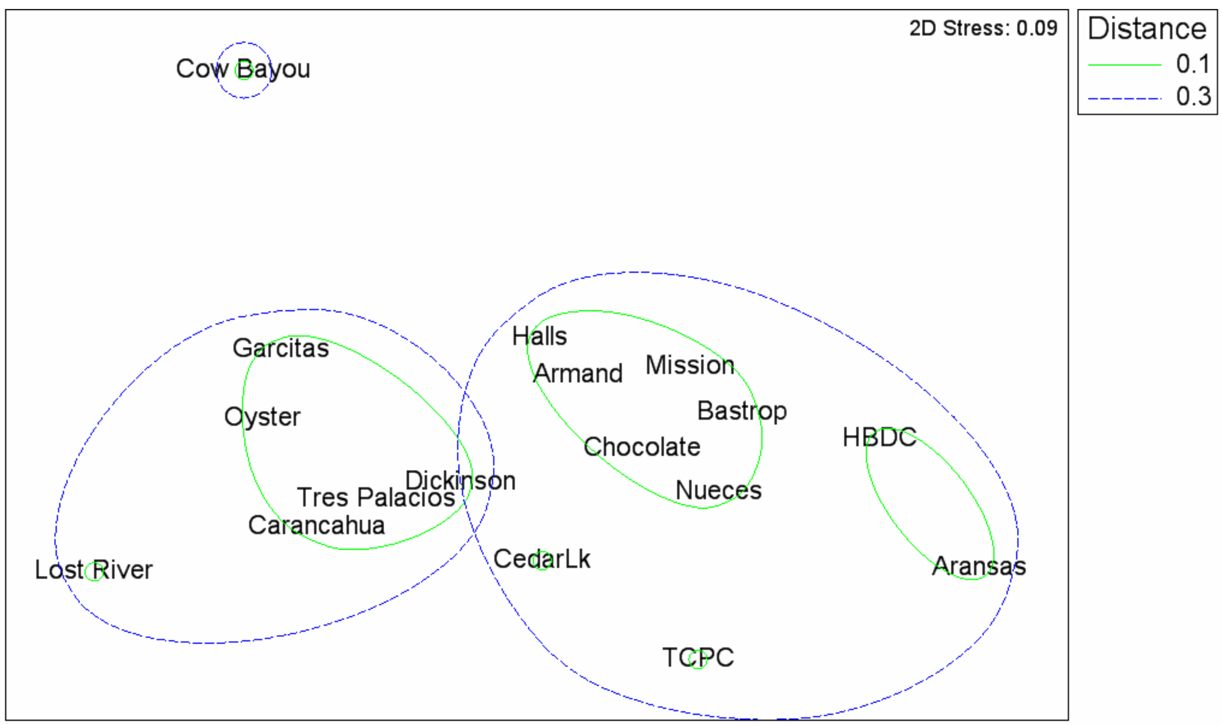


Figure 5. Multidimensional scaling ordination means plot of the tidal streams based on surface measurements of Field parameters. Streams within a common ellipse are not significantly different at the α = 0.1 level (dashed line) and the α = 0.05 level (solid line). Distance based on Euclidean distances of pairwise similarity measures taken from a complete linkage Cluster Analysis of the complete similarity matrix (not shown).

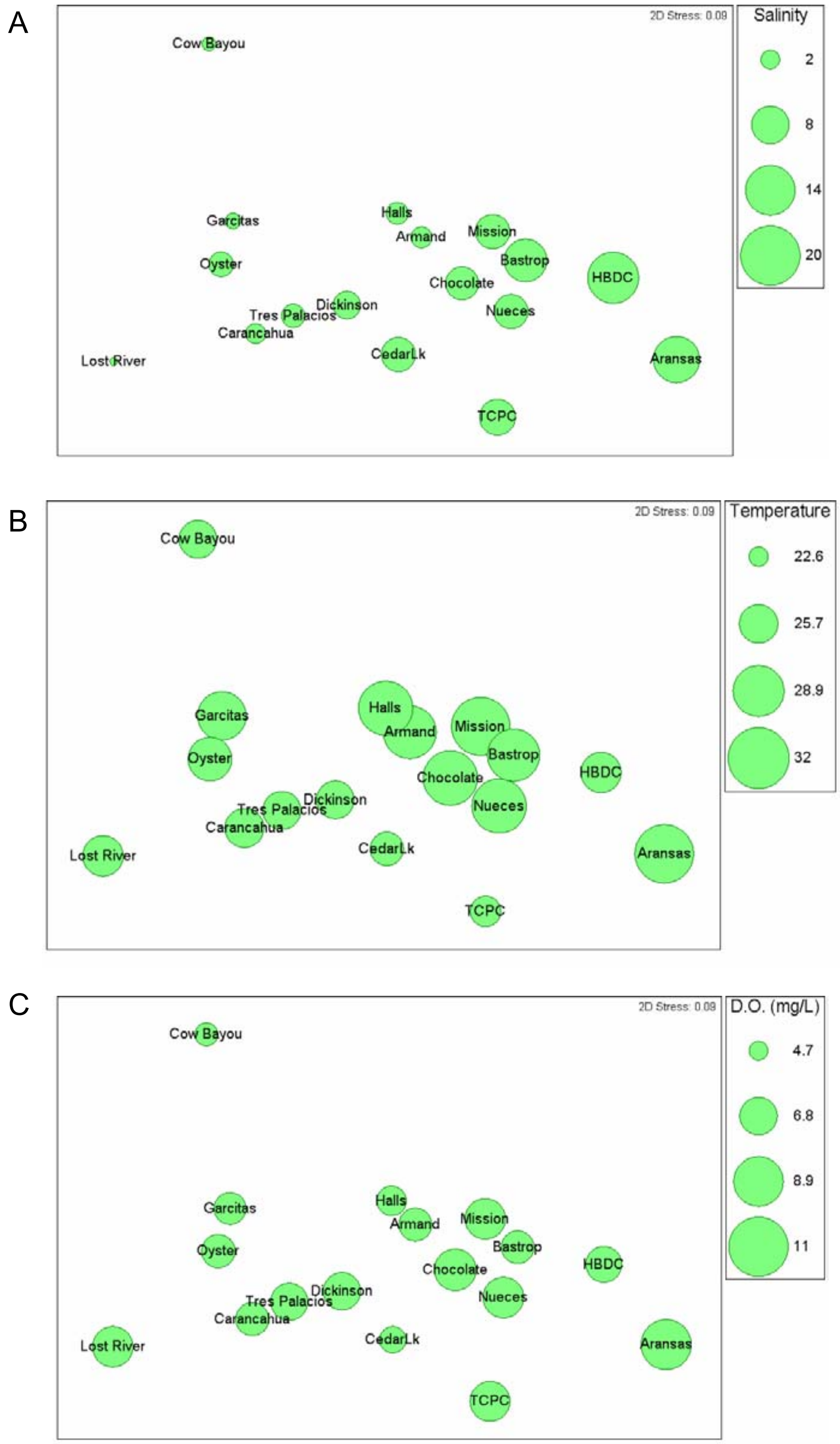


Figure 6. Multidimensional scaling ordination means plot of the tidal streams based on surface measurements of Field parameters. Overlaid onto each plot are the mean salinity (A), temperature (B), and dissolved oxygen concentrations (C) recorded from each tidal stream.

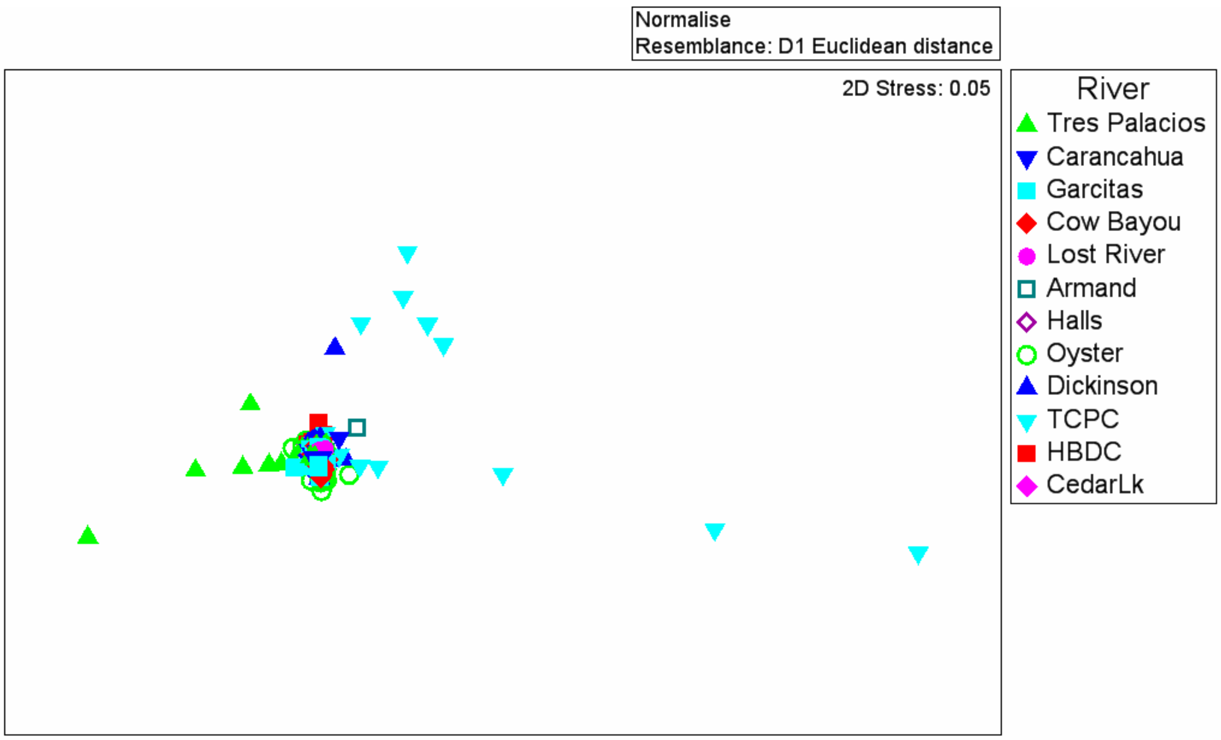


Figure 7. Multidimensional scaling ordination of the tidal stream locations based on surface measurements of Conventional parameters.

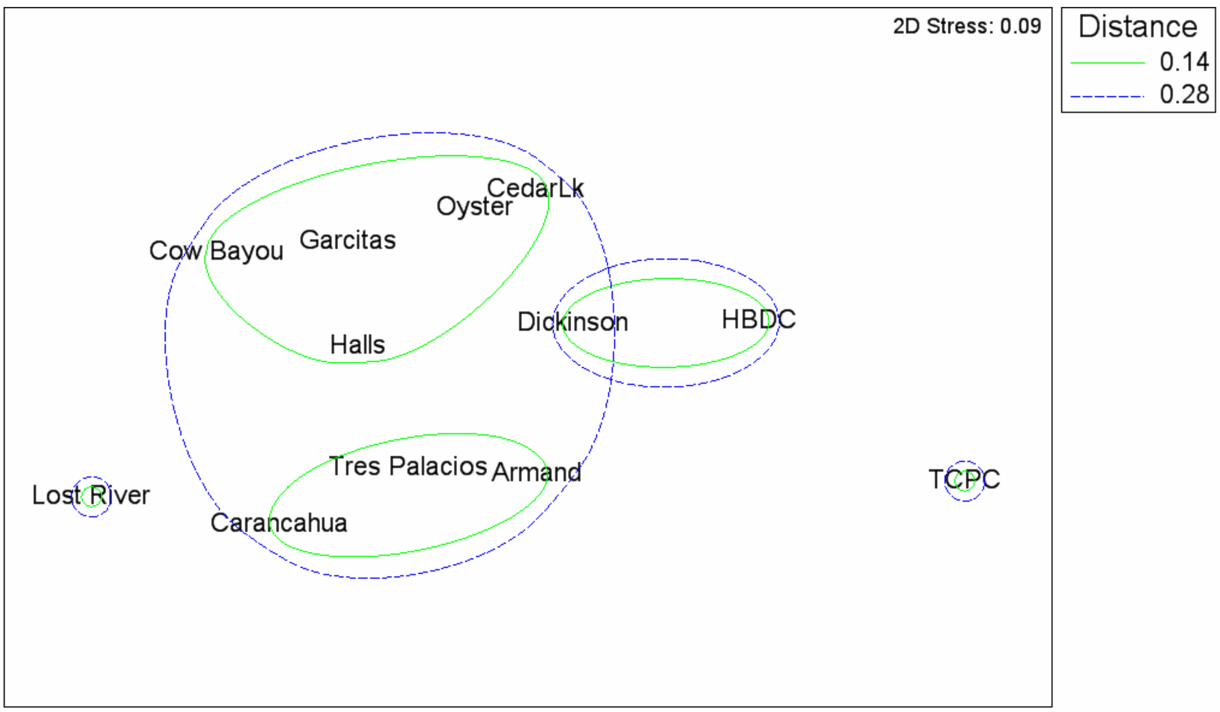


Figure 8. Multidimensional scaling ordination means plot of the tidal streams based on surface measurements of Field parameters. Streams within a common ellipse are not significantly different at the α = 0.1 level (dashed line) and the α = 0.05 level (solid line). Distance measure follows the and Euclidean distance measure outlined in Fig. 5

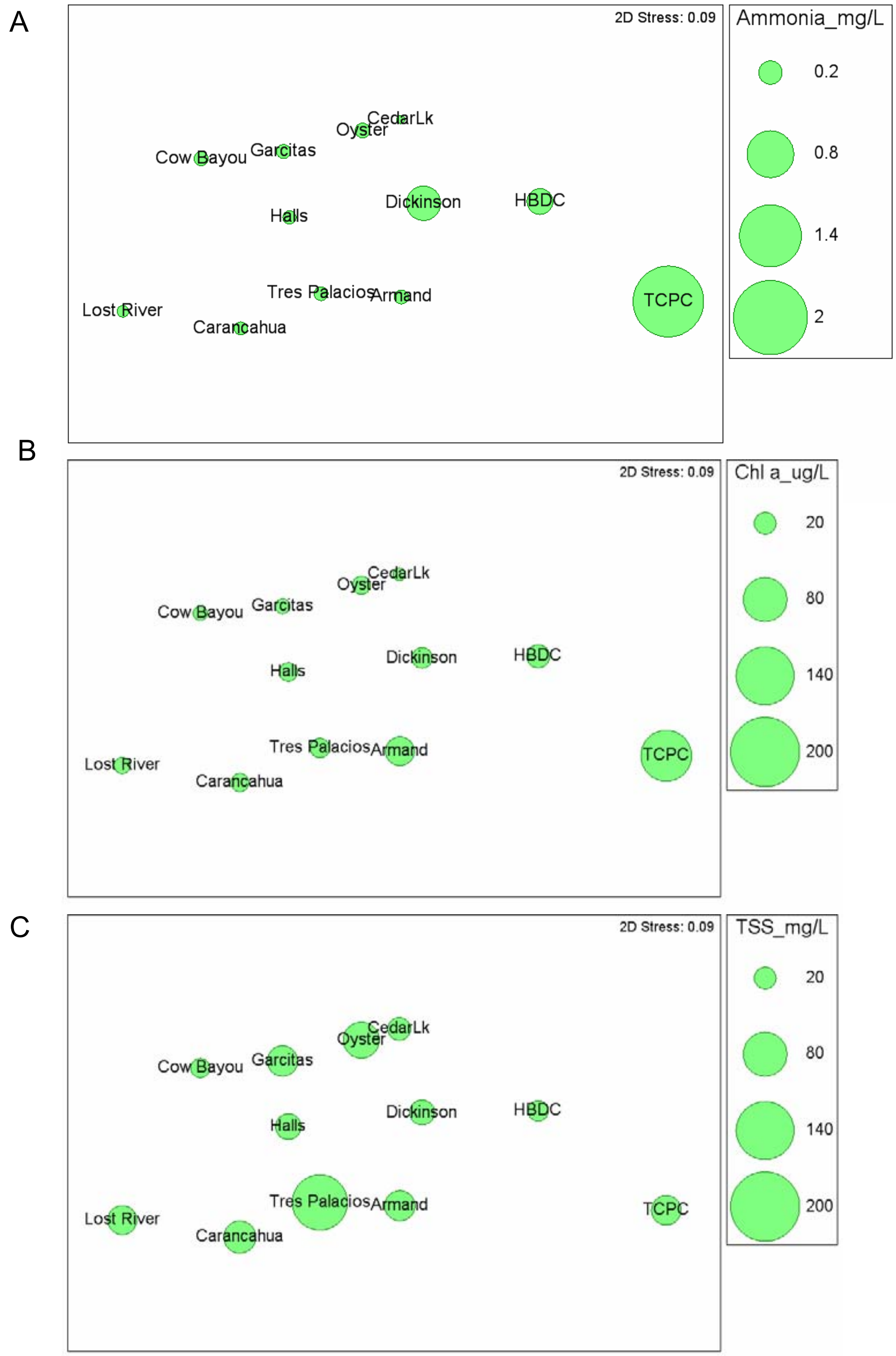


Figure 9. Multidimensional scaling ordination means plot of the tidal streams based on surface measurements of routine Field parameters. Overlaid onto each stream are the mean ammonia (A), chlorophyll a (B), and total suspended solids concentrations (C) recorded from each tidal stream

A

B

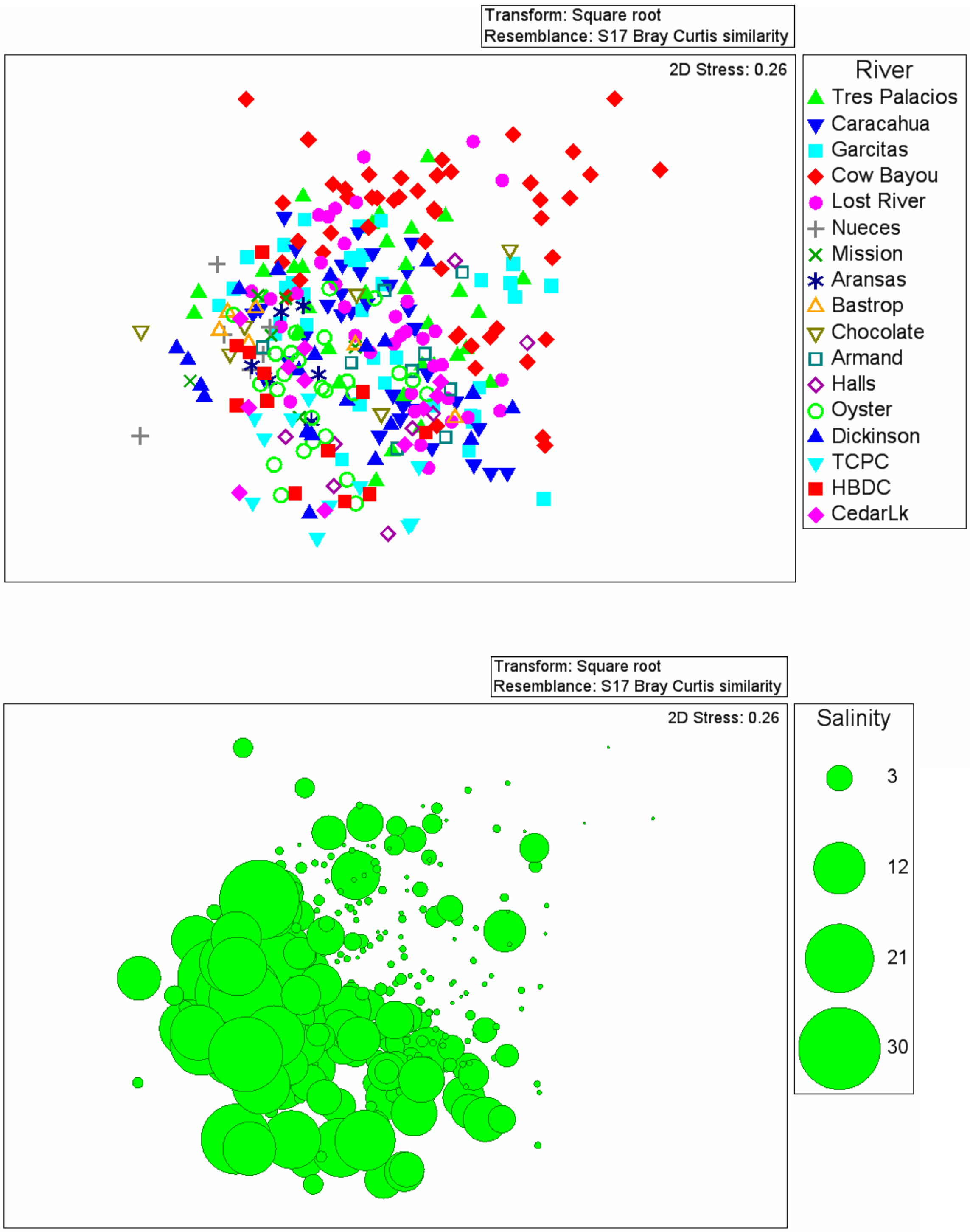


Figure 10. Multidimensional scaling ordination of the tidal stream locations based on community structure recorded with the bag seine collections (A), with individual salinity measurements overlaid onto each sampling event (B).

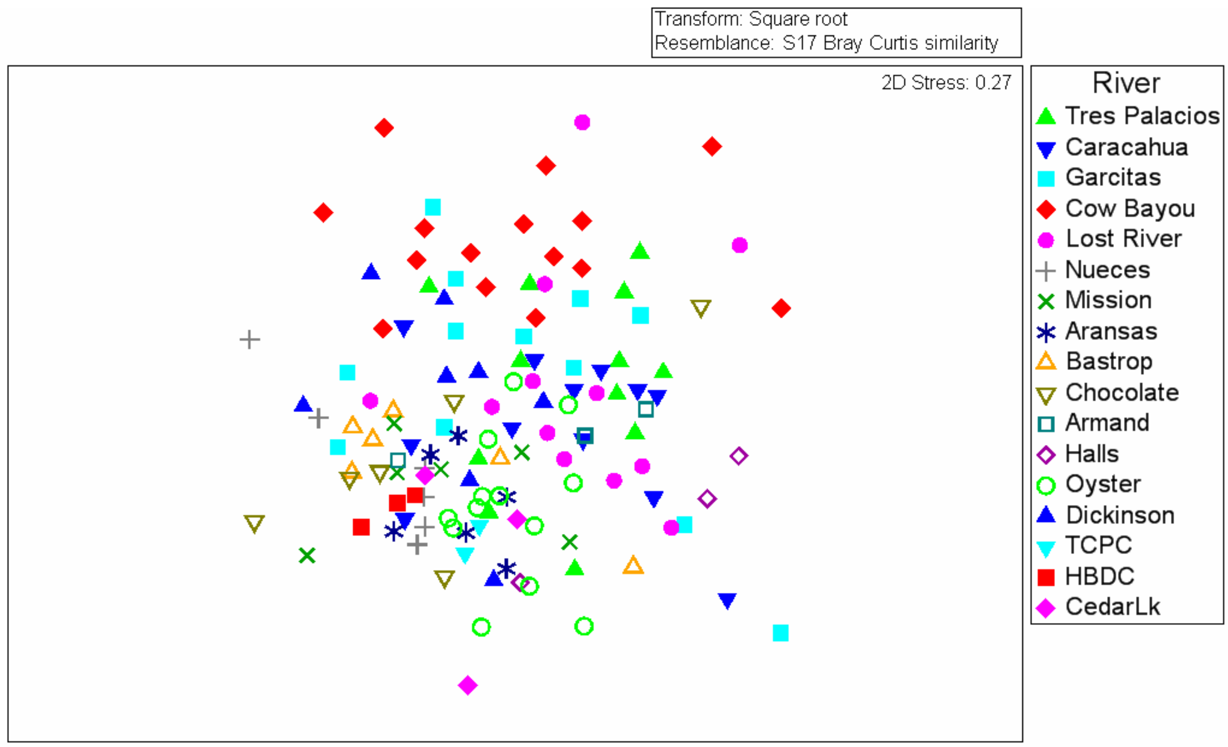


Figure 11. Multidimensional scaling ordination of the tidal stream locations based on community structure recorded with the bag seine collections taken during the summer season.

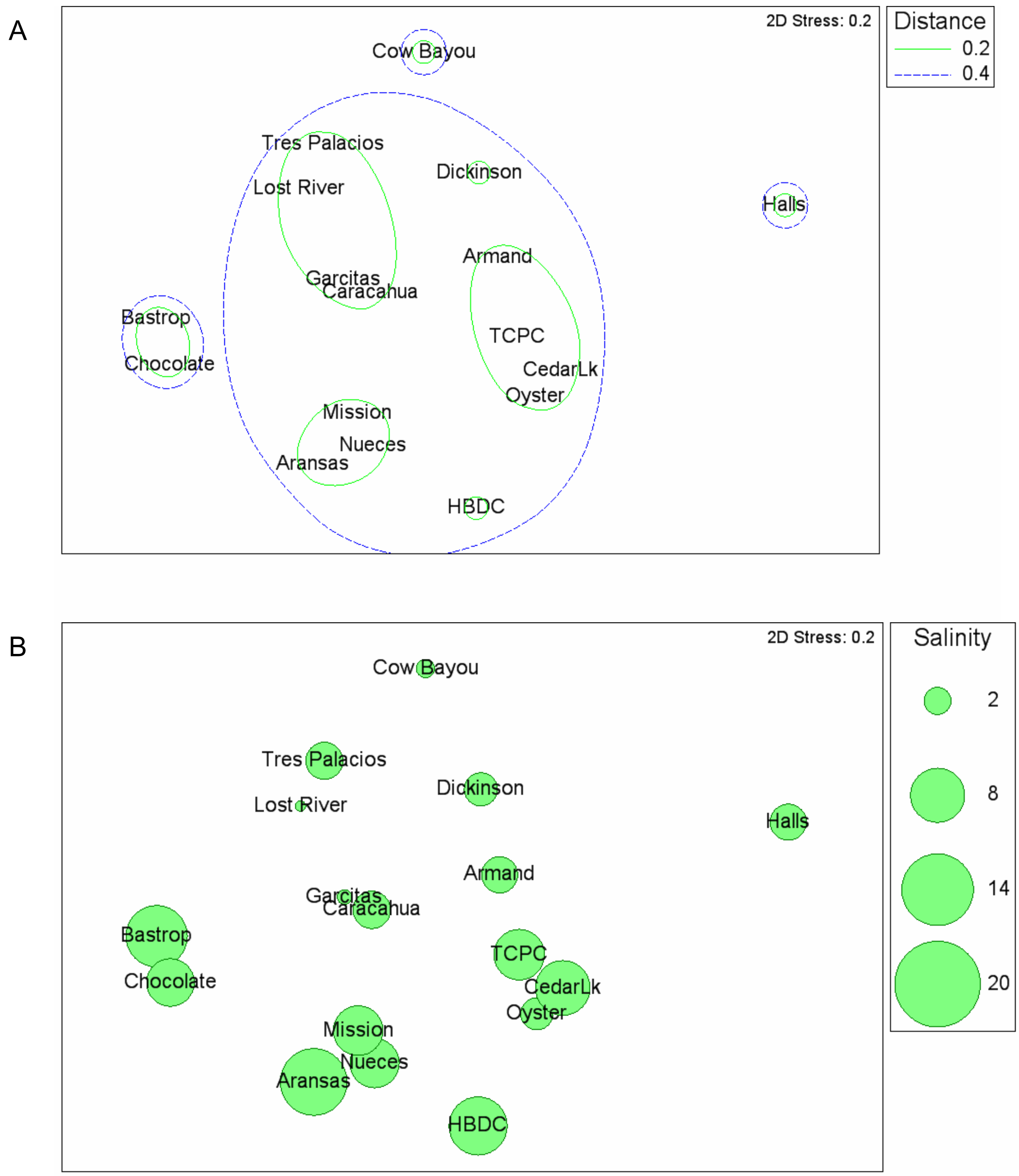


Figure 12. Multidimensional scaling ordination means plot of the tidal streams based on the community structure recorded with the summer-season bag seine collections (A). Overlaid onto each stream is the mean salinity recorded during the summer collections (B). Distance measures in (A) follow the α value and Euclidean distance measure outlined in Fig. 5.

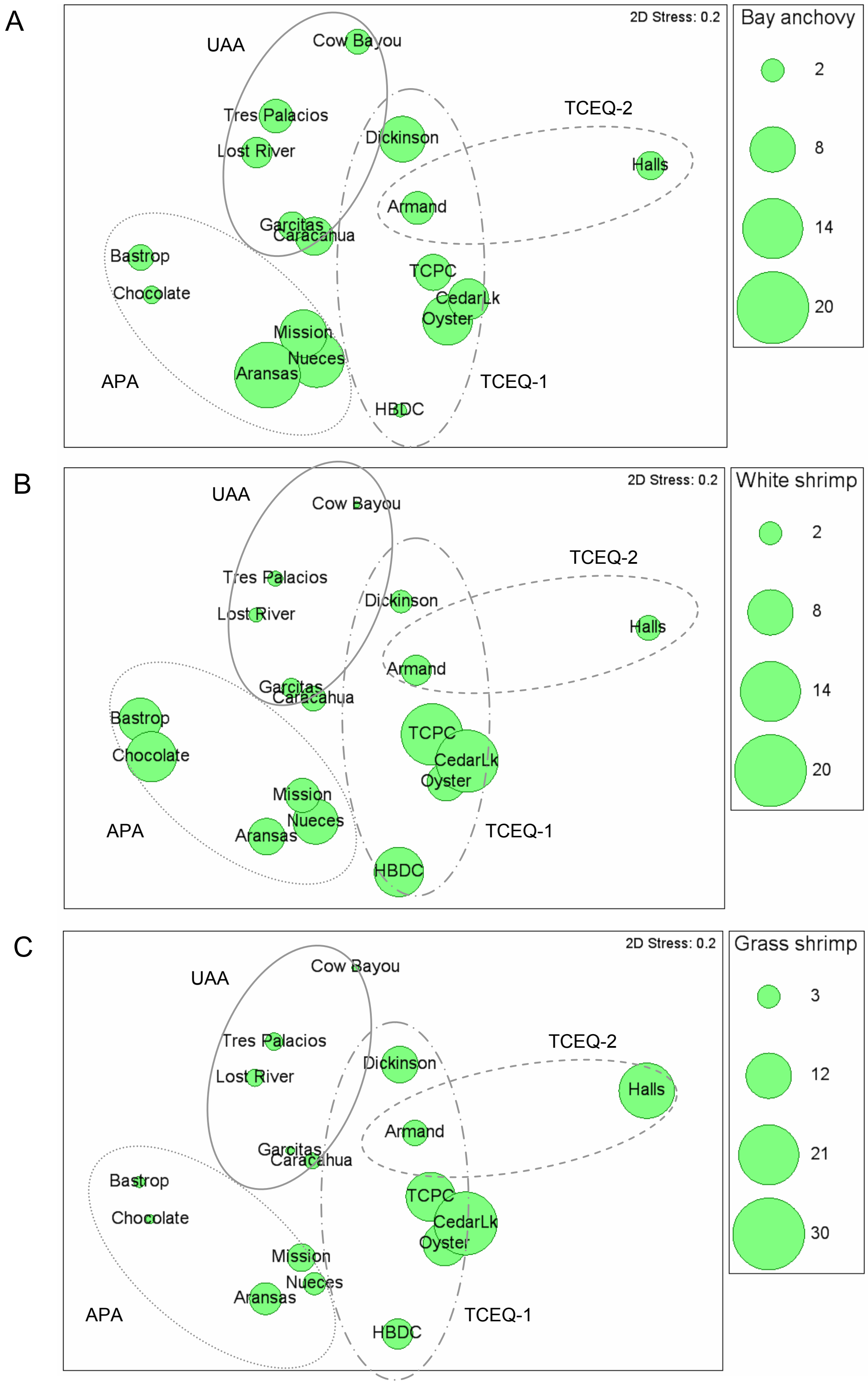


Figure 13. MDS ordinations as in Fig. 12, overlaid with abundance levels of bay anchovy (A), white shrimp (B), and grass shrimp (C) recorded with summer season bag seine efforts. Common studies streams surrounded by ellipses.

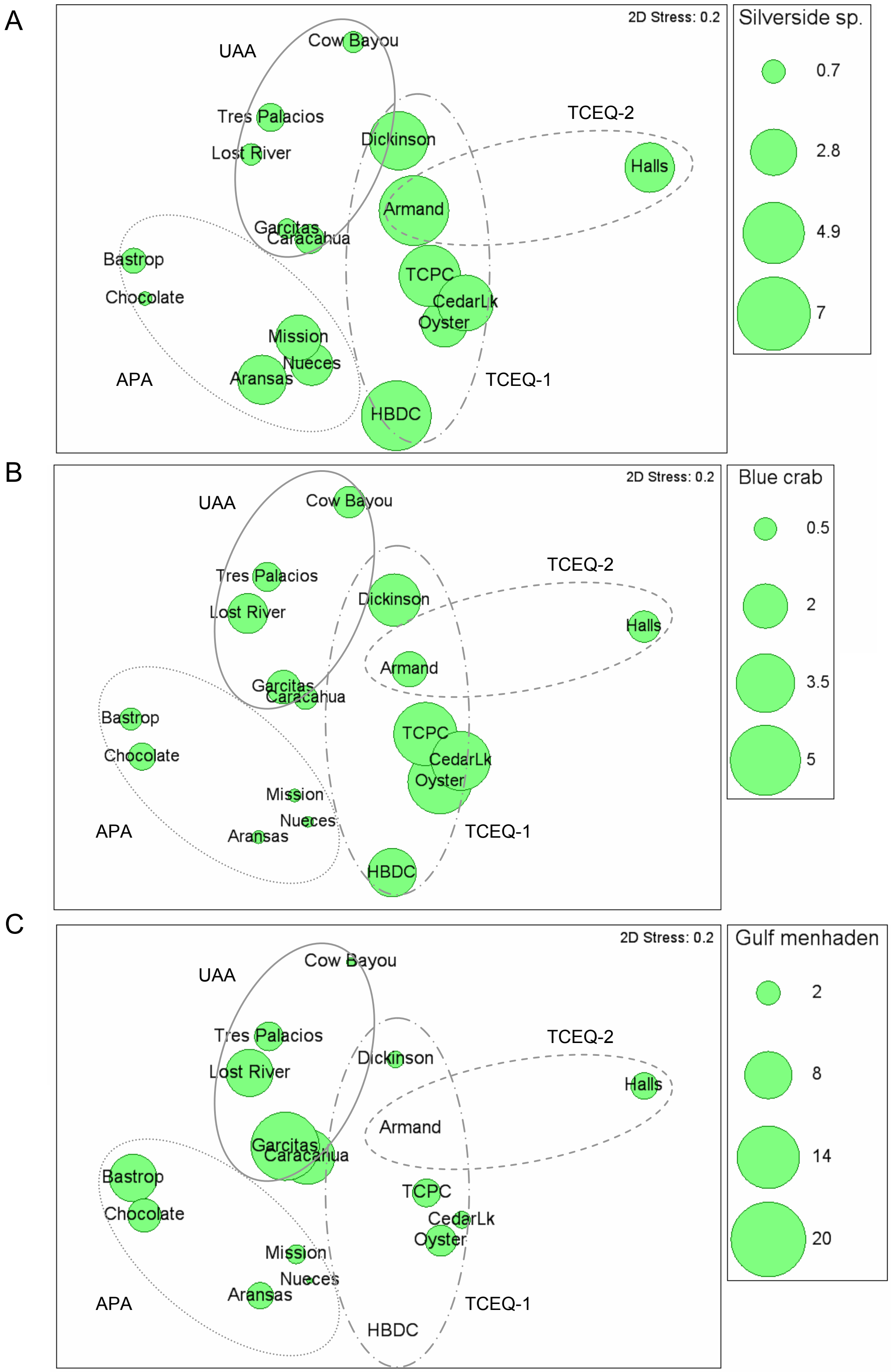


Figure 13 (cont). Overlays of abundance levels of silversides (A), blue crab (B), and Gulf menhaden (C).

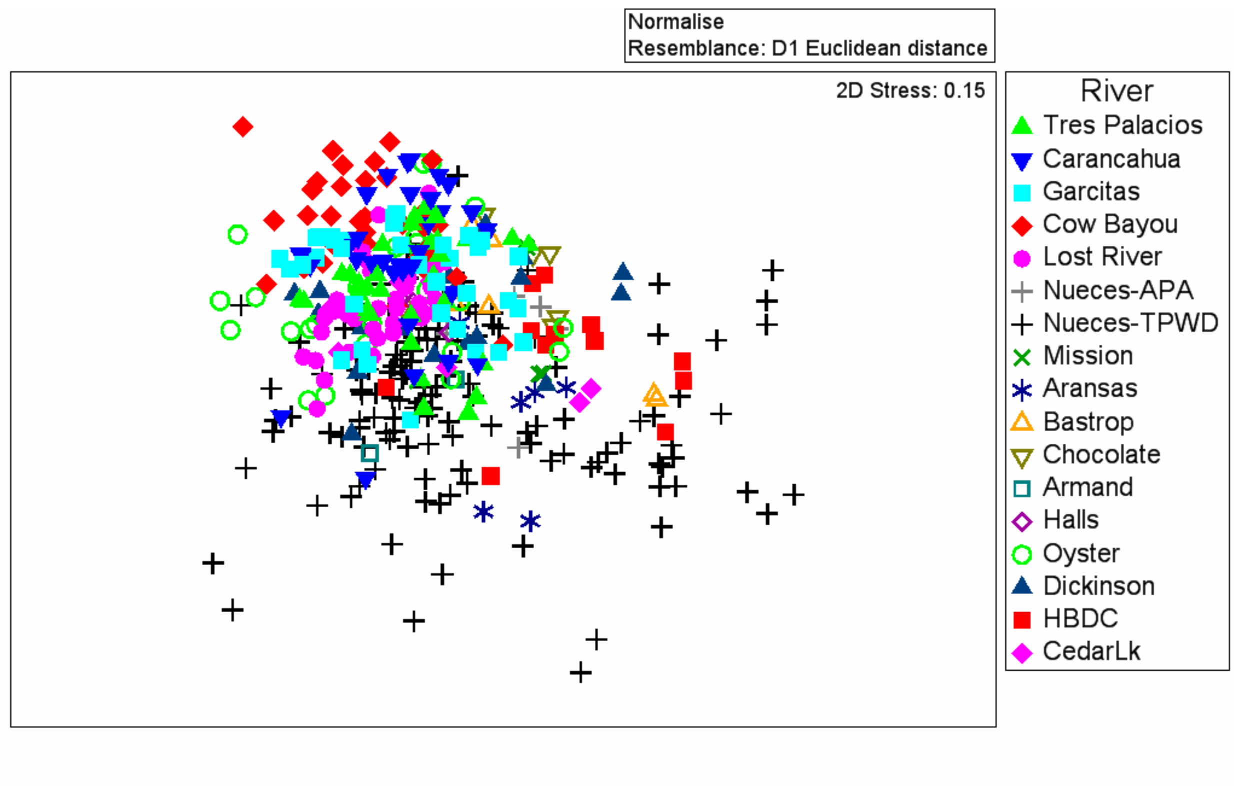


Figure 14. Multidimensional scaling ordination of the tidal stream locations based on bottom measurements of routine Field parameters

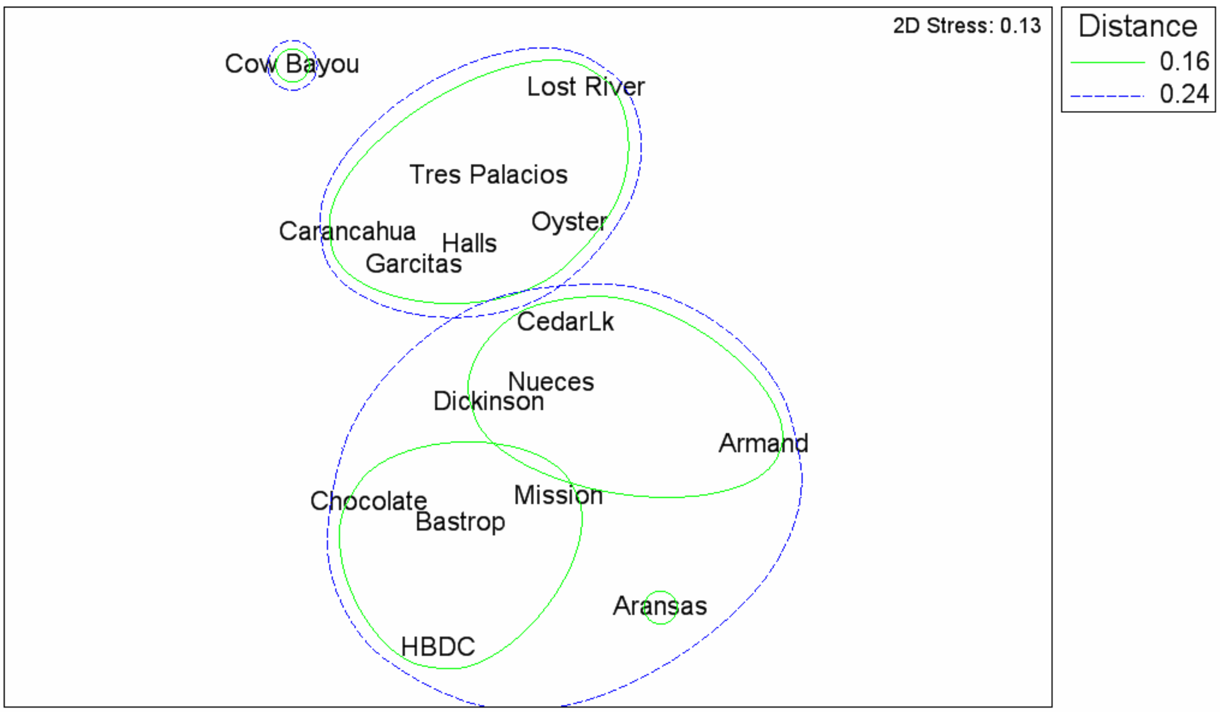


Figure 15. Multidimensional scaling ordination means plot of the tidal streams based on bottom measurements of routine Field parameters. Streams within a common ellipse are not significantly different at the α = 0.1 level (dashed line) and the α = 0.05 level (solid line). Distance measures follow the Euclidean distance measure outlined in Fig. 5.

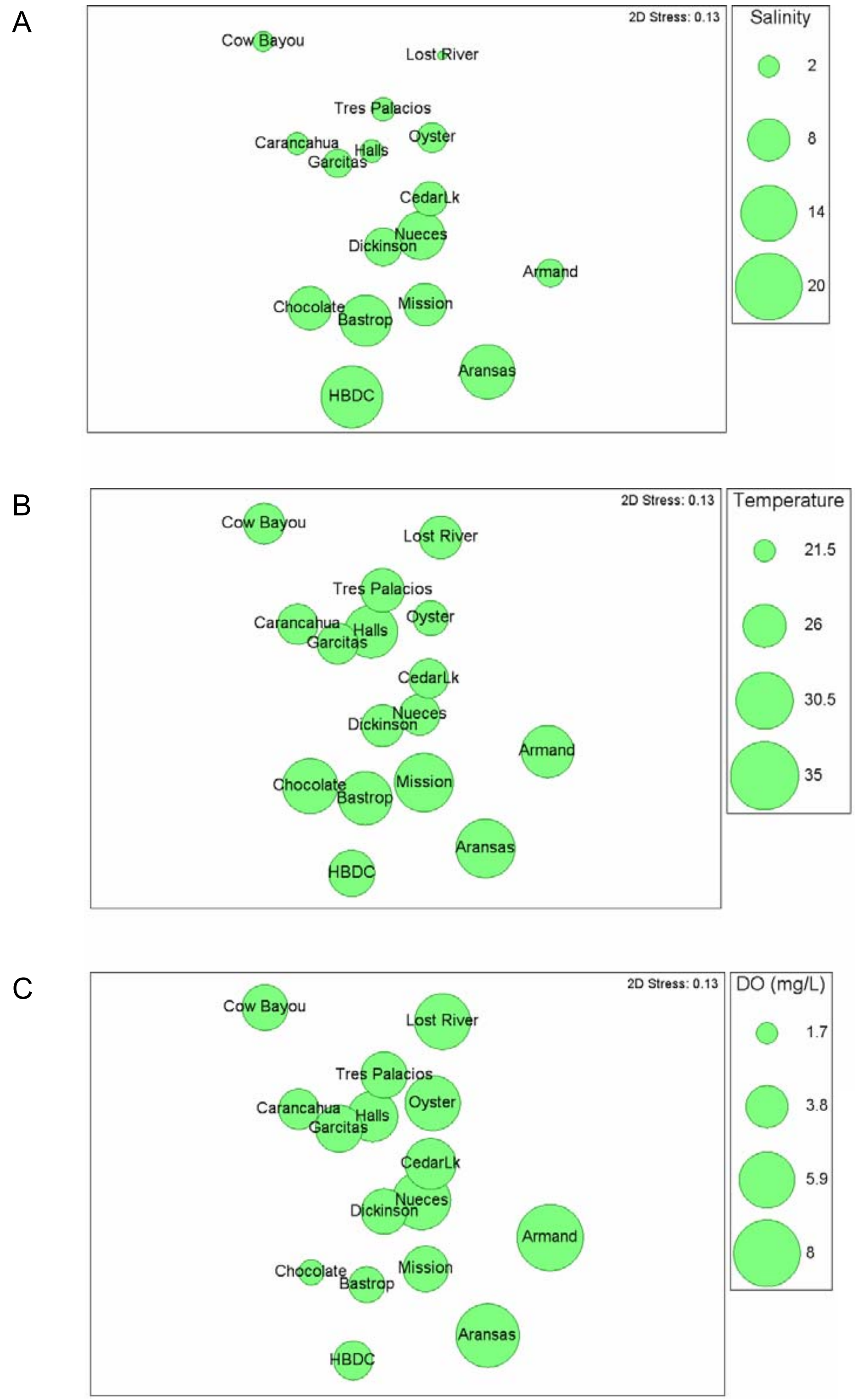
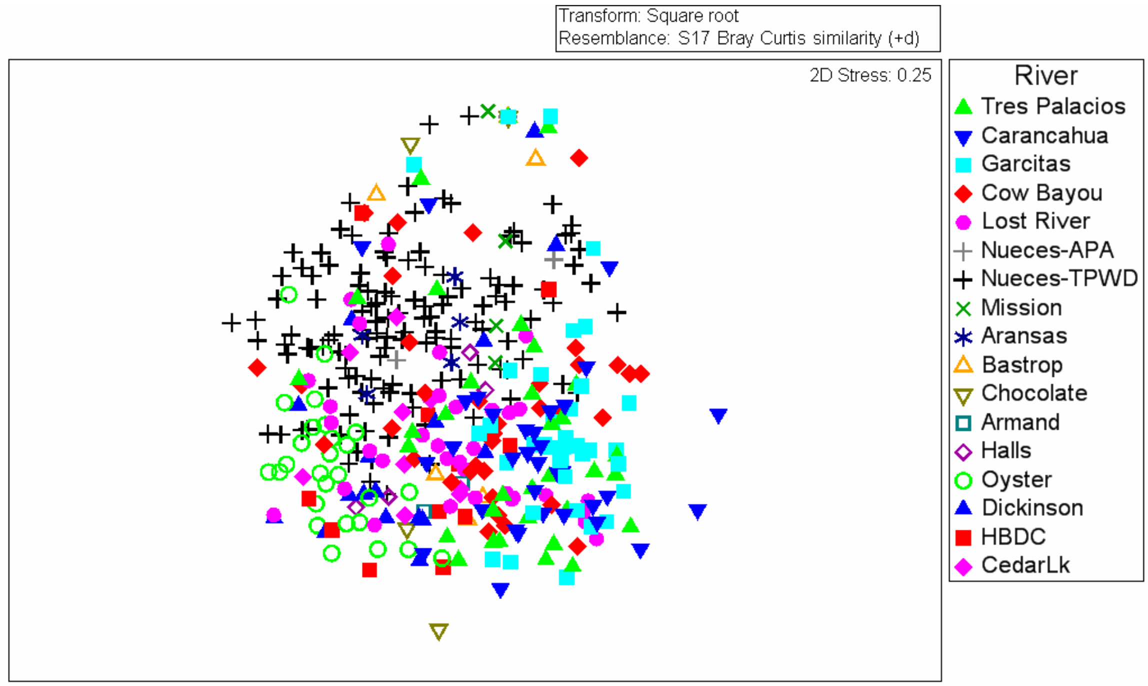


Figure 16. Multidimensional scaling ordination means plot of the tidal streams based on bottom measurements of routine Field parameters. Overlaid onto each plot are the mean salinity (A), temperature (B), and dissolved oxygen concentrations (C) recorded from each tidal stream

A



B

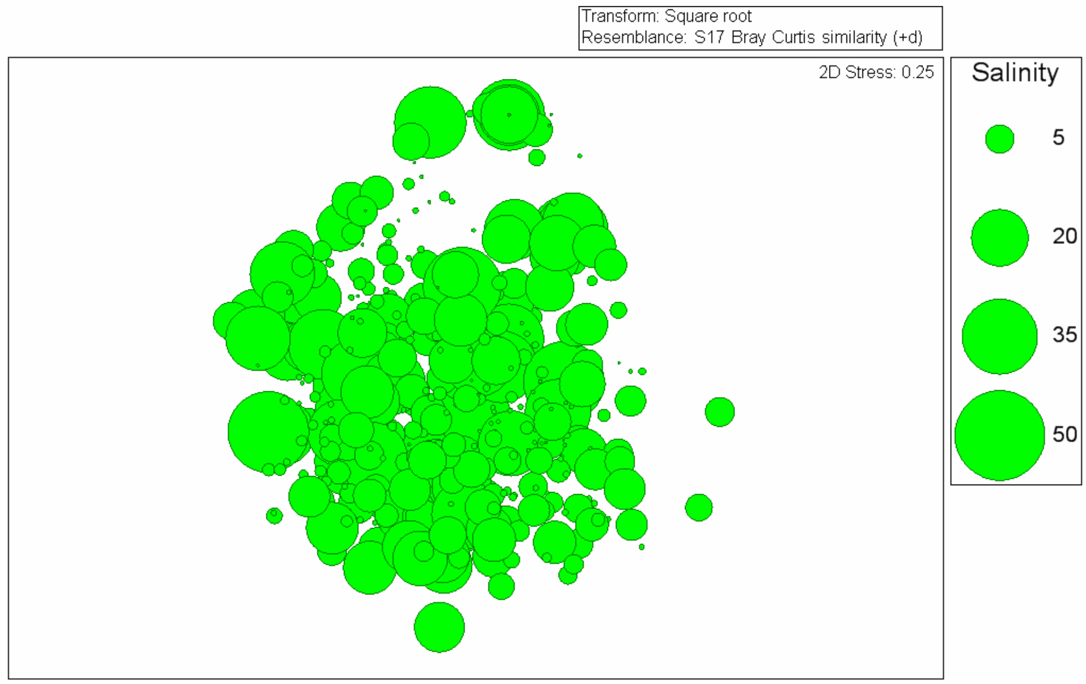


Figure 17. Multidimensional scaling ordination of the tidal stream locations based on community structure recorded with the otter trawl collections (A), with individual salinity measurements overlaid onto each sampling event (B).

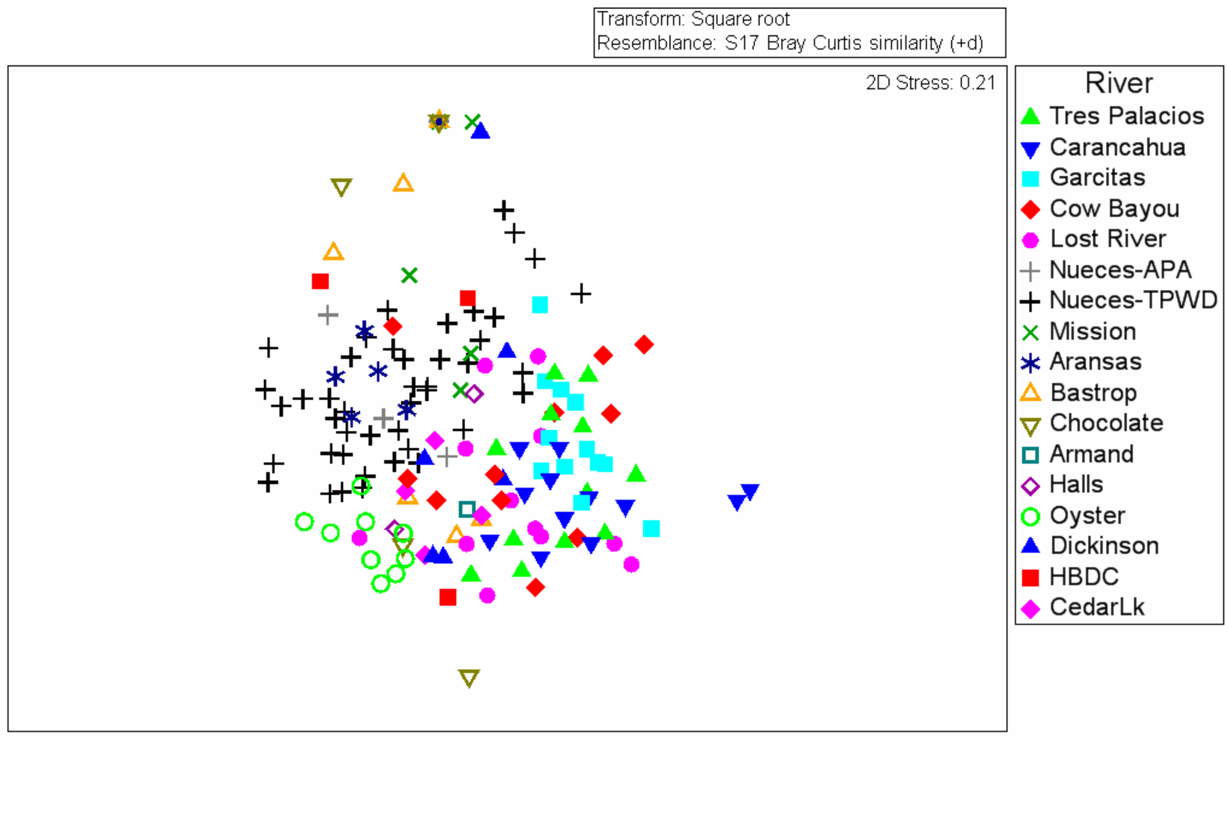


Figure 18. Multidimensional scaling ordination of the tidal stream locations based on community structure measured with the otter trawl collections taken during the summer season.

A

B

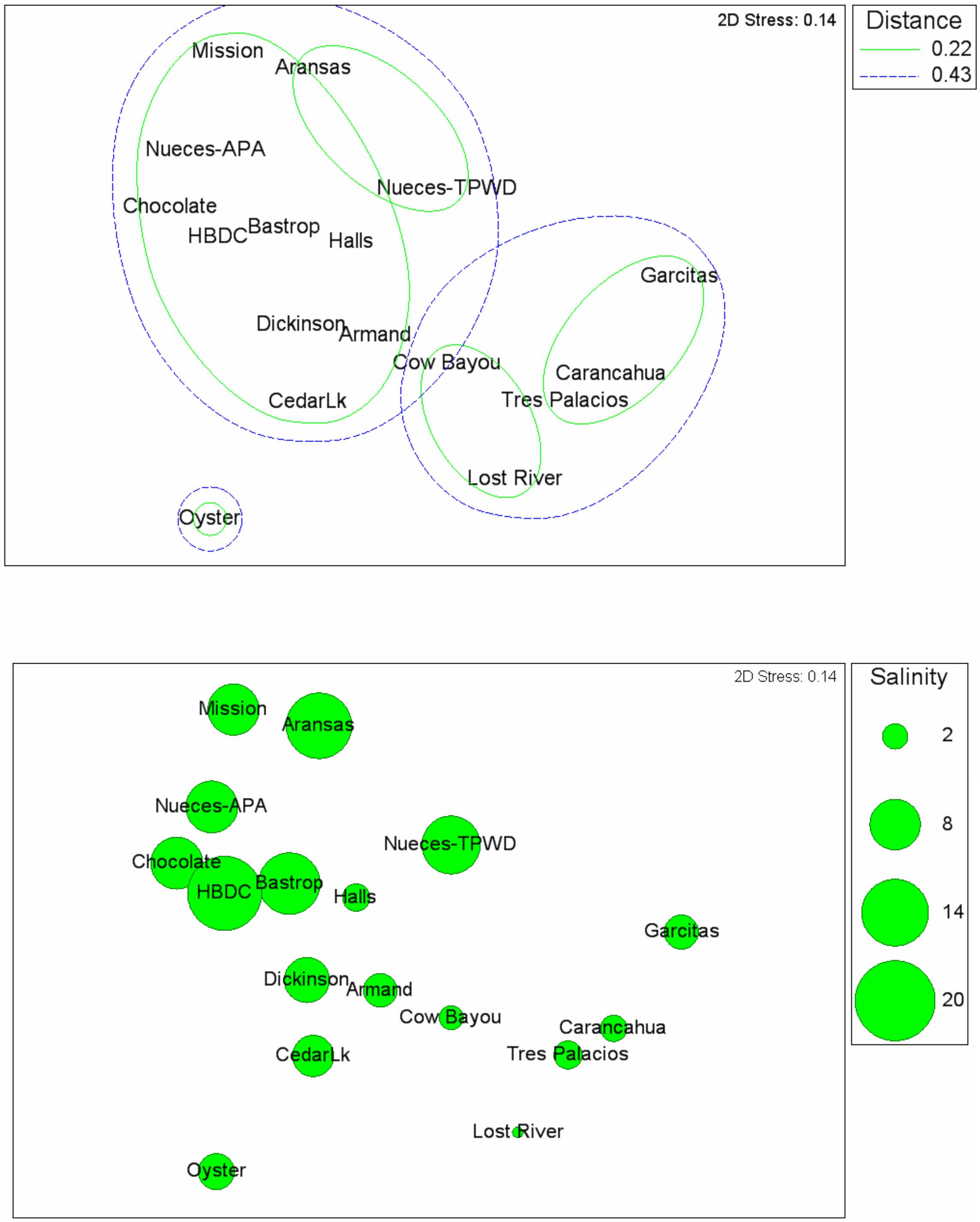


Figure 19. Multidimensional scaling ordination means plot of the tidal streams based on the community structure recorded with the summer-season otter trawl collections (A). Overlaid onto each stream is the mean salinity recorded during the summer collections (B). Distance measures in (A) follow the α value and Euclidean distance measure outlined in Fig. 5.

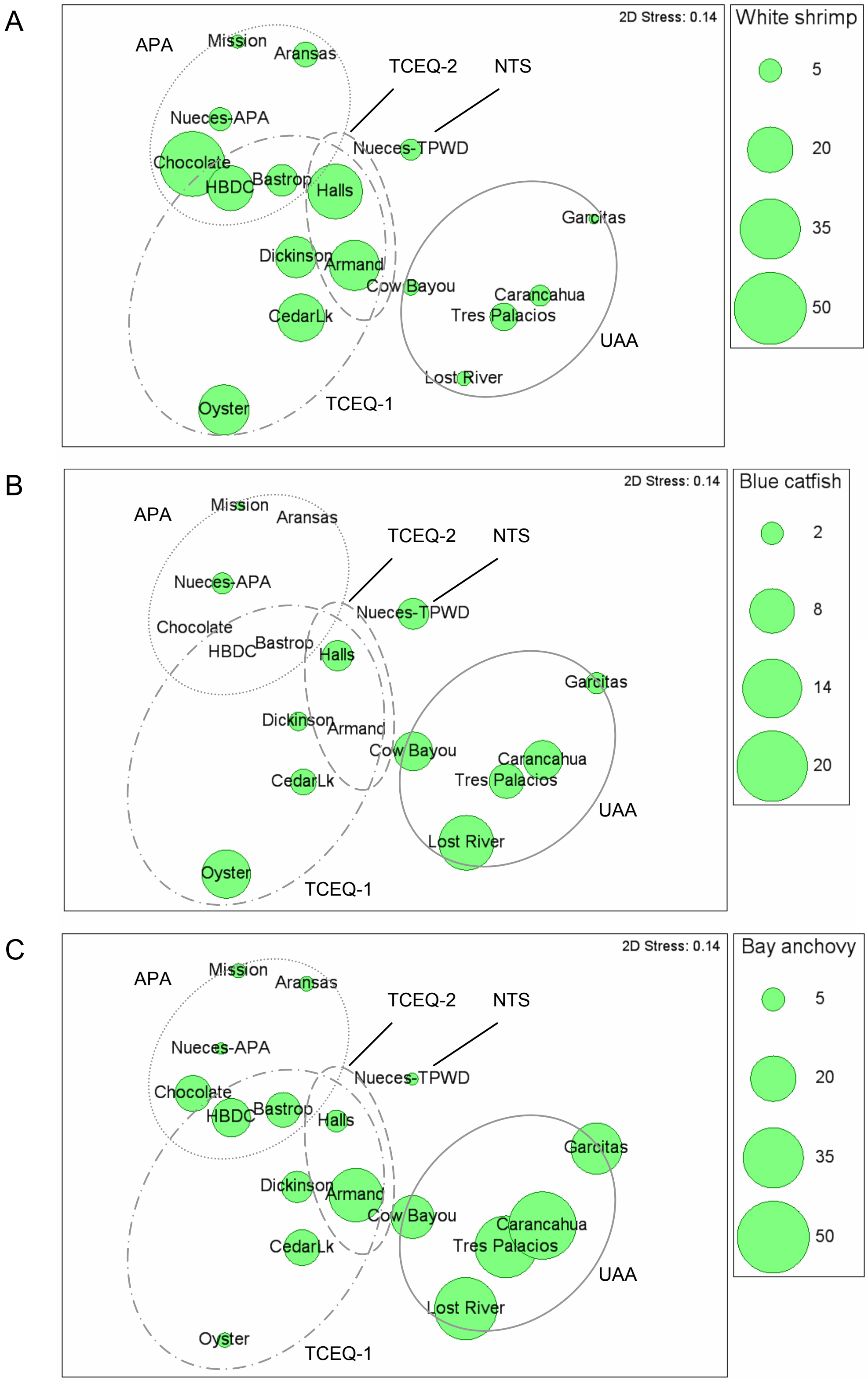


Figure 20. MDS ordinations as in Fig. 19, overlaid with abundance levels of white shrimp (A), blue catfish (B), and bay anchovy (C) recorded with summer season otter trawl efforts. Common studies streams surrounded by ellipses.

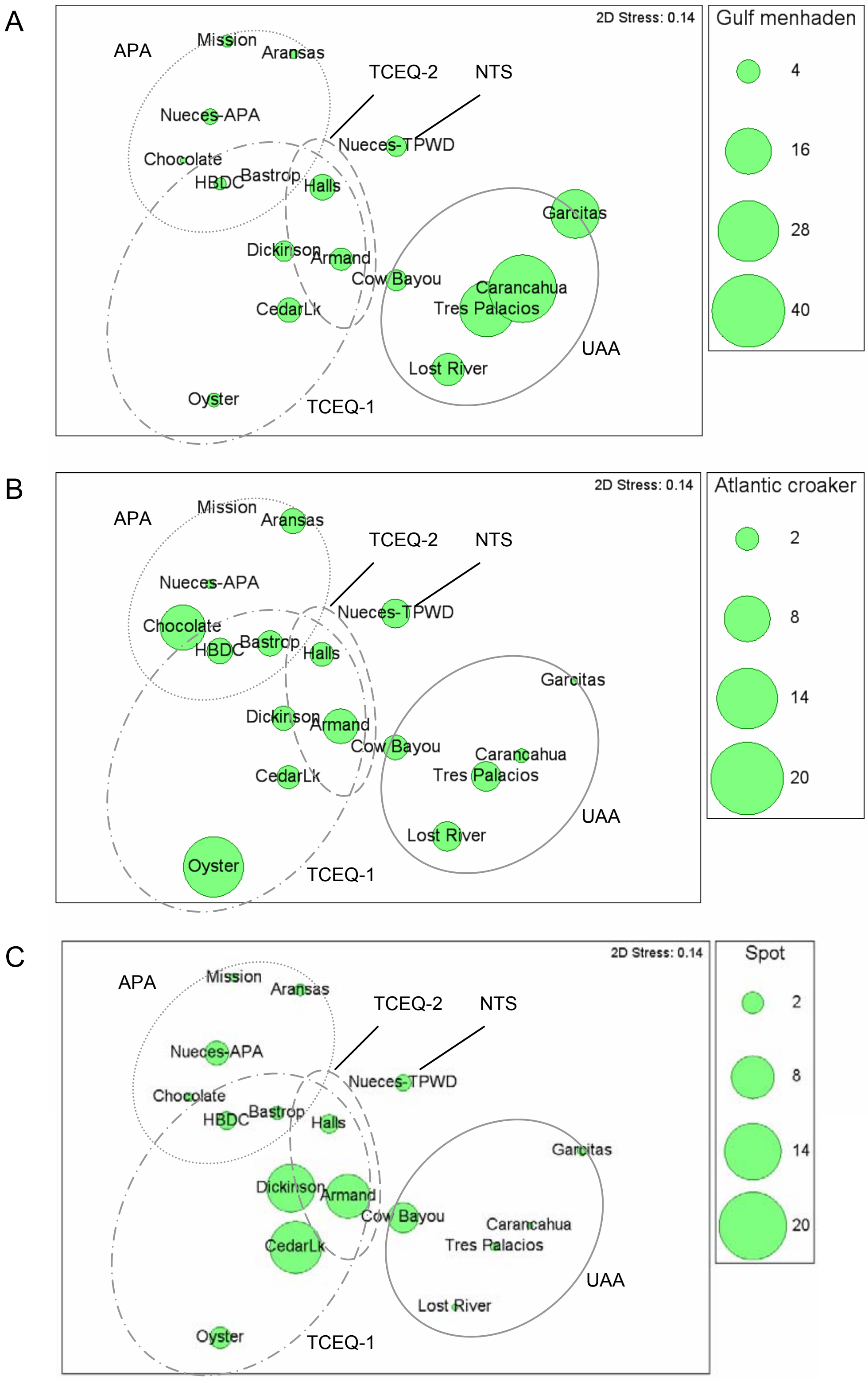


Figure 20 (cont). Overlays of abundance levels of Gulf menhaden (A), Atlantic croaker (B), and spot (C).

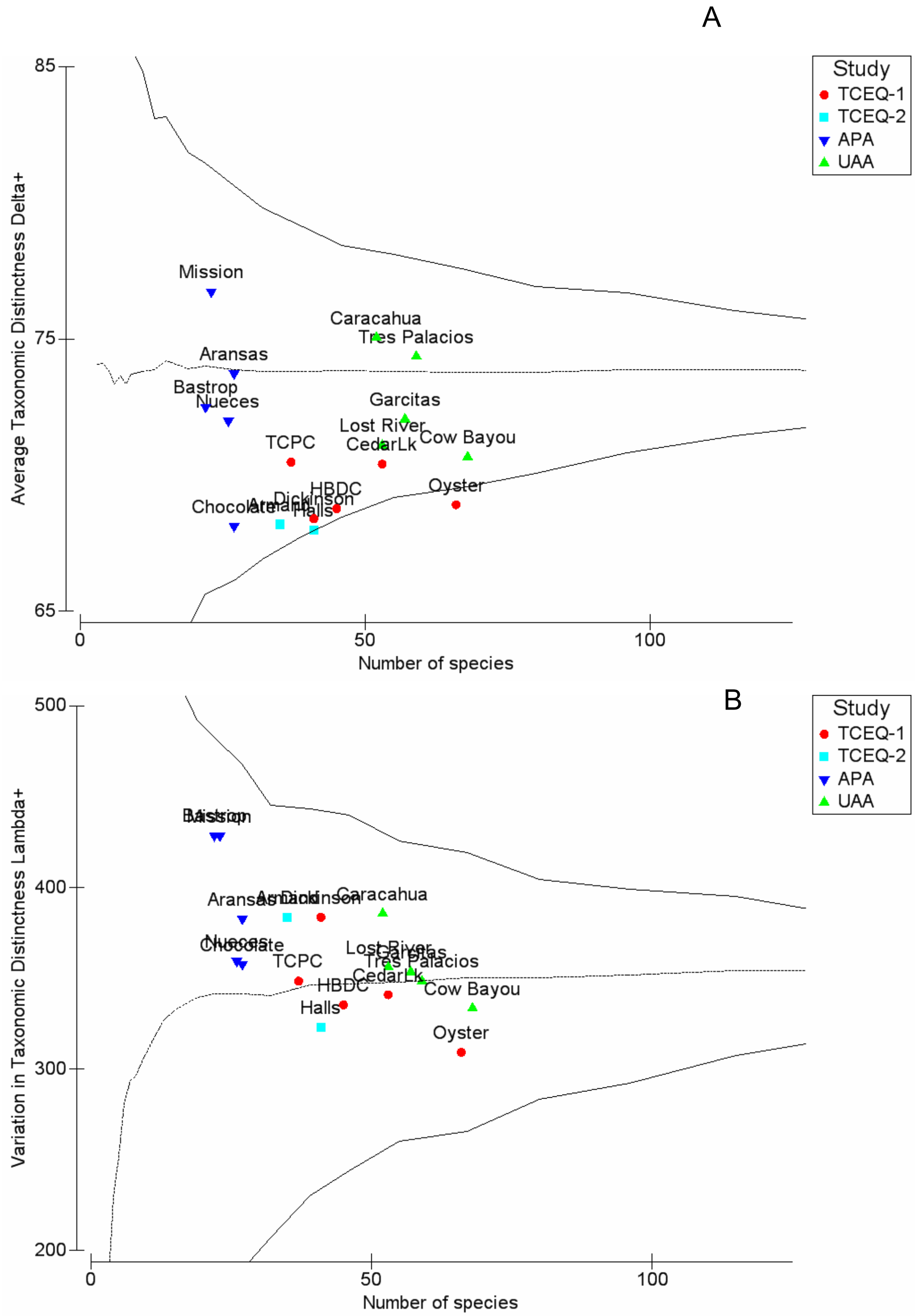


Figure 21. Funnel plot for simulated Average Taxonomic Distinctness (A) and Variation in Taxonomic Distinctness (B), from 999 sublists drawn randomly from a Texas Tidal Stream master list of 191 taxa. Upper and lower control lines represent the 95% probability limits of the simulated values; thin line indicates mean Taxonomic Distinctness. Points color-coded by study are the true Average Taxonomic Diversity values of bag seine collections from the 17 study streams, plotted against their sublist size.

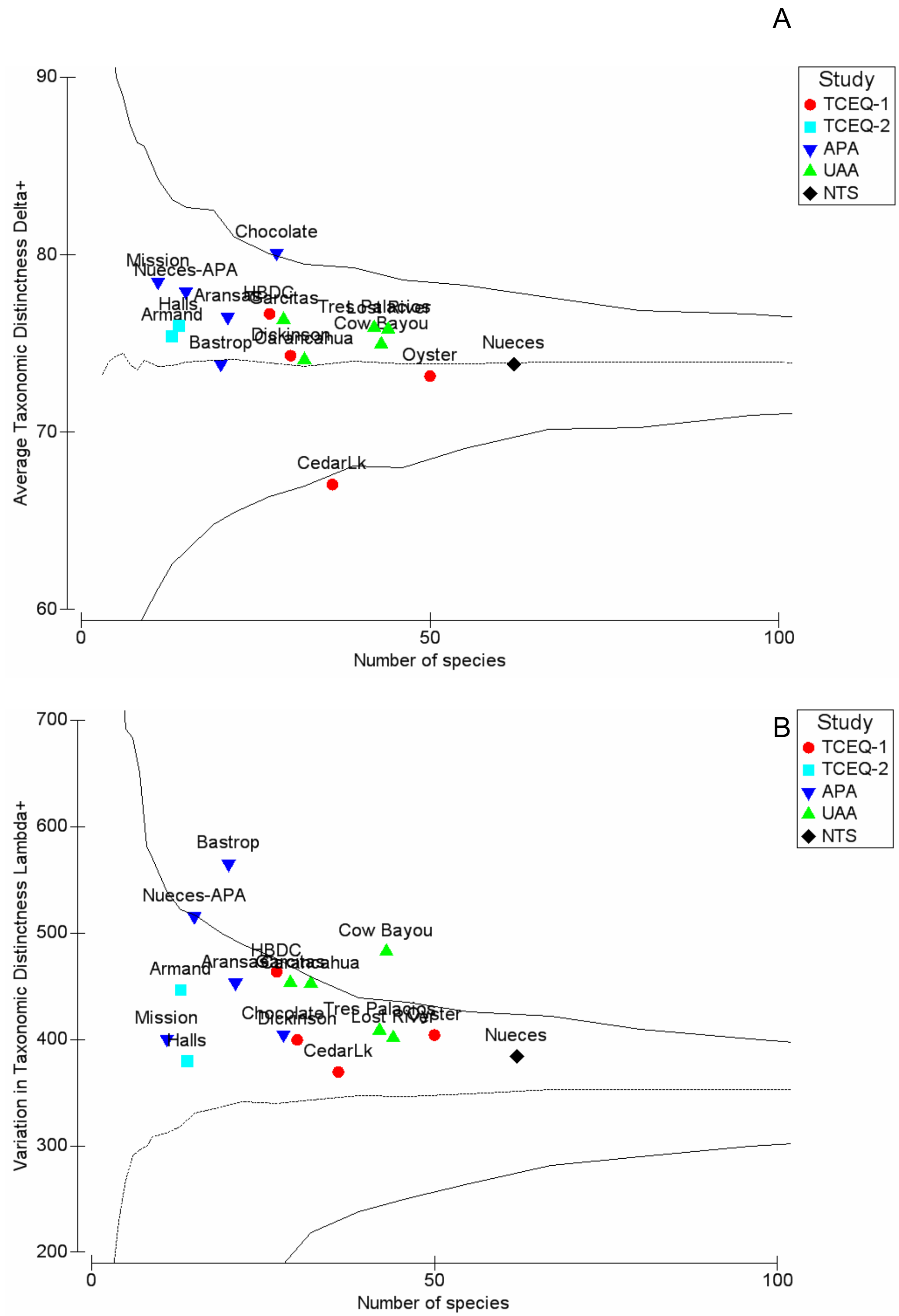


Figure 22. Funnel plot for simulated Average Taxonomic Distinctness (A) and Variation in Taxonomic Distinctness (B), from 999 sublists drawn randomly from a Texas Tidal Stream master list of 191 taxa. Upper and lower control lines represent the 95% probability limits of the simulated values; thin line indicates mean Taxonomic Distinctness. Points color-coded by study are the true Average Taxonomic Diversity values of otter trawl collections from the 16 study streams, plotted against their sublist size.