SPATIAL ASSESSMENT OF A DERIVED BIOCRITERIA

APPLIED TO TEXAS TIDAL STREAMS

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

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Date 14 DEC 11

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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 this project. Special thanks go to Jason Leifester, Office of Water, TCEQ, for shepherding the original UAA and Mission-Aransas Studies, and believing enough in this multivariate analysis technique to allow this work to be performed. Additionally, I would like to thank Linda Broach (TCEQ) for proving digital copies of the fishery and environmental data from the large number of historical studies her agency performed of the upper Texas coast. Thanks also go to the many TPWD staff who participated on the Nueces Trawl Survey. This work could not have been undertaken without the additional support provided by Janet Nelson (TPWD). Her efforts as project Budget Officer, as well as lead investigator on two of the tidal streams under investigation, provided significant amounts of both logistical and field support to the completion of this work.

INTRODUCTION

The importance of estuaries as nursery grounds for a variety of marine organisms is well documented (Beck, 2001; Le Pape et al., 2003; Martinho et al., 2009).; with the variety of habitat types within estuaries providing larval and juvenile organisms some degree of protection from piscivory during their early life history stages (i.e., egg, pre- and post-flexion, pelagic juveniles). The increased rates of primary production that are typically found in estuaries has been linked to nutrient loadings via freshwater inputs (Valiela et al., 1997), and this overall productivity is maintained by complexes of emergent vegetation, benthic algae, and phytoplankton, all of which can efficiently utilize these nutrients. Because nearly all marine fishes are obligately dispersed in the plankton during their early life history stages, planktonic propagules face the challenge of locating and settling into suitable estuarine habitat for successful recruitment. The majority of estuarine-dependent fishery organisms spawn either offshore or in the nearshore pelagic realm, and the recruitment success of the planktonic stages can subsequently affect the community structure of adult populations; many of which are recreationally and/or commercially important.

Tidal streams are highly productive transitional areas found in the mixing zones between the freshwater of the rivers and the increased salinities found within the estuary. Tidal streams also serve as important nursery areas for many fish and shellfish species, and a number of species have been shown to actively recruit to these important habitats (Hoese and Moore, 1992; Tolan, 2008). Routine monitoring of several tidally influenced segments throughout the State of Texas have revealed that water quality standards are not currently being met (TCEQ, 2008). Tidal segments listed on the 2010 303(d) list are routinely cited as having increased bacterial loads and depressed dissolved oxygen measurements, and these excursions of low dissolved oxygen waters could have a detrimental effect on the early life history stages of finfish and shellfish utilizing these nursery areas. Water quality management of these areas has been difficult because currently there are no state-wide criteria for assessing tidally influenced waterbodies, and these systems are naturally quite variable over time and space.

Numerous tidal streams are included on the state's list of impaired water-bodies (TCEQ 2010). 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 of the six studies that formed the basis of this expanded assessment are fully detailed in Tolan (2008). Briefly, the TCEQ studies 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 (TCEQ-1; Guillen, 1996), and Armand Bayou and Halls Bayou from April 2002 until June 2003 (TCEQ-2; L. Broach, Texas Commission on Environmental Quality, unpublished data). Alan Plummer and Associates (APA, 1997) sampled water quality and nekton from the tidal portions of the middle coast (Nueces, Aransas, and Mission Rivers) and upper coast (Bastrop and Chocolate Bayous) during a single summer season in 1995. This study is referred to as the Water Quality Study (WQS). A second study on the Nueces River Tidal (TPWD, unpublished data) measuring water quality and otter trawl-only nekton collections took place from October 1996 to November 2001 and will be identified as the Nueces Trawl Survey (NTS) The UAA Studies by TPWD (Contreras and Whisenant., 2007; 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 from April 2003 until November 2004. A second set of UAA-type studies were conducted by TPWD on the tidal portions of the Mission and Aransas Rivers (TIDAL2; Tolan et al., 2010). Sampling protocols for Tolan et al. (2010) followed those for the original UAA studies, save for the exclusion of gill nets and electrofishing efforts. The three studies that concentrated sampling efforts on the Arroyo Colorado and Rio Grande Tidal segments are referred to as the Lower Coast Studies (LCS), and all are shown in Fig. 1.

Descriptions of the 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 0.8 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: mid-channel, right quarter point, and left quarter point. Depth profiles during the September sampling event was reduced to mid-channel only. Nekton sampling consisted of otter trawls (N = 6) and 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.

TPWD occupied 3 fixed sampling locations on the Mission River from March 2008 until November 2009 as part of their TIDAL2 efforts. These three stations (which were all located in the general proximity to the original locations used for the APA (1997) work) were occupied twice each spring, summer, and fall this study. No sampling took place during the winter. Trawling and seine collections for motile biota were performed at all the stations, with a total of 36 samples for each gear collected. Gill nets and electrofishing techniques were not included as part of this study. Each sampling event also recorded depth profiles of routine Field parameters, as well as the full suite of Conventional parameters.

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.

TPWD occupied 3 fixed sampling locations on the Aransas River from March 2008 until November 2009 as part of their TIDAL2 efforts. Each of the stations for the TIDAL2 work was located much farther upstream than the original locations used for the APA (1997) work. The uppermost station for the TIDAL2 study was approximately 12 km farther upstream from their original upper station; the middle station was 10 km farther upstream; and the lower station was 5 km farther upstream. These stations were occupied twice each spring, summer, and fall for this study. No sampling took place during the winter. Trawling and seine collections for motile biota were performed at all the stations, with a total of 36 samples for each gear collected. Gill nets and electrofishing techniques were not included as part of this study. Each sampling event also recorded depth profiles of routine Field parameters, as well as the full suite of Conventional parameters.

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 13.7 km 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.

Arroyo Colorado Tidal

Segment 2201, from confluence with the Laguna Madre in Cameron/Willacy County to a point 100 meters downstream of Cemetery Road south of Port Harlingen in Cameron County (Fig. 1). Each of the areas of 2201_03 (from the confluence with an unnamed drainage ditch at 97.53 N - 26.31 W to the confluence with Harding Ranch Ditch), 2201_04 (from the confluence with Harding Ranch Ditch tributary to just upstream of the City of Rio Hondo Wastewater Discharge at 97.58 N - 26.25 W), and 2201_05 (from just upstream of the City of Hondo Wastewater Discharge to the upstream end of the segment) were listed in 2006 for bacteria. Areas 2201_04 and 2201_05 were also listed in 2006 for depressed dissolved oxygen. Area 2201_05 is additional listed for mercury in edible tissue (2008), and PCB's in edible tissue (2008). A TMDL specifically addressing the depressed dissolved oxygen impairment (TCEQ TMDL Segment 2201, 2003) found that the endpoint target of 90% compliance of the dissolved oxygen standard was met only after a 90% reduction in loadings of constituents of concern was achieved (namely nitrogen, phosphorus, and BOD). The TMDL found that physical properties of the segment, including the Port of Harlingen, manipulated by dredging and other mechanical changes to the river, all contribute to this impairment. At times, barge traffic to the Port causes the anoxic water near the bottom of the channel to rise to the surface which can result in fish kills. This work ultimately lead to the development of the Arroyo Colorado Watershed Protection Plan (ACWPP, 2007).

Sampling on the Arroyo Colorado consisted of two separate studies, taking place between May 1989 and December 2003. Landry and Harper (1980) occupied three stations during the spring, summer, and fall of 1989, and these same three stations were also sampled during the winter of 1990. The upper station was located at river-km 21 from the confluence with the Laguna Madre; the middle station located at river-km 12, and the lower station was located at river-km 0. These locations correspond to areas 2201_01 to 2201_03 within the Segment. Seine and trawl collections were performed at every station, for a total of 12 collections each. Gill net collections were also done in conjunction with the seines and trawls, resulting in 12 total collections. Electrofishing was not included in this study. Each sampling event also recorded depth profiles of Temperature, Salinity, and Dissolved Oxygen concentration. Conventional water chemistry parameters were not recorded for this study.

TPWD conducted monthly sampling at numerous sites within Segment 2201, from January 2001 until December 2003. Instead of fixed locations, monthly sampling points were randomly chosen from the established TPWD grid (1 nautical mile X 1 nautical mile, see Martinez-Andrade and Fisher, 2010) within the tidal portions of Segment 2201. Using the river-km designations as determined in the Landry and Harper study (1990), sampling locations for the

TPWD Arroyo Colorado Special Study ranged from river-kilometer 0 to river-km 37, and overlapped their upper, middle, and lower locations, although the TPWD study ranged farther upstream, nearly to the end of area 2201_4. Seine sampling resulted in 216 collections, and trawl sampling resulted in an additional 431 collections. Each collection was accompanied by either a surface water (seines) or bottom water (trawls) recording of Temperature, Salinity, Turbidity, Depth, and Dissolved Oxygen concentration. Neither gill nets nor electrofishing operations were undertaken in this study. Conventional water chemistry parameters were not recorded for this study.

Rio Grande Tidal

Segment 2301, from confluence with the Gulf of Mexico to a point 10.8 km downstream of the International Bridge in Brownsville, Cameron County (Fig. 1). The tidal segment is 79 river-km in length, and currently there are no impairments, although closer to the Gulf there are high chlorophyll-a levels (TCEQ 2010). The 2010 assessment used *Enterococcus* as the bacteria indicator, showing a concern for bacteria levels. Sampling on the Rio Grande Tidal consisted of same two studies as on the Arroyo Colorado, although sampling by Landry and Harper (1990) was extended until April of 1990 on the Rio Grande. Their upper station was located at river-km 32, the middle station located at river-km 13, and the lower station at river-km 0. Seine collections in this study were not as uniform on the Arroyo Colorado Tidal, with the middle station collections not being recorded in May of 1989 and also April of 1990. A total of 13 beg seine collections comprised this study. Similar levels of effort were recorded for the Trawl collection (N = 13) and the gill net collections (N = 13). Electrofishing was not included in this study. Each sampling event also recorded depth profiles of Temperature, Salinity, and Dissolved Oxygen concentration. Conventional water chemistry parameters were not recorded for this study.

TPWD sampling efforts on Segment 2201included monthly bag seine and trawl samples from January 1992 until December 1997, and a second effort of these same gears from May 2001 until April 2002. In both efforts, monthly sampling points were randomly chosen from the established TPWD grid. Sampling locations for the TPWD Rio Grande Tidal Special Study ranged from river-km 0 to river-km 43, and overlapped with the Landry and Harper (1990) upper, middle, and lower locations. Similar to the TPWD Arroyo Colorado Special Study, the TPWD sampling locations on the Rio Grande Tidal ranged farther upstream. Bag seine sampling resulted in 419 collections, and trawl sampling resulted in an additional 698 collections. Each collection was accompanied by either a surface water (bag seines) or bottom water (trawls) recording of Temperature, Salinity, Turbidity, Depth, and Dissolved Oxygen concentration. Neither gill nets nor electrofishing operations were undertaken in this study. Conventional water chemistry parameters were also not recorded for this 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.). Distinctions among stations (in terms of their biological communities, and their physical and chemical properties), as well as their differences among locations, 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 among impaired and unimpaired conditions provides the basis for the assessment.

What was not seen in the original UAA studies (Contreras and Whisenant, 2007; Tolan et al., 2007) 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 aforementioned multivariate techniques to a number of historical datasets collected from varying degrees of "impacted" tidal streams; and determine to what extent the biological communities can be used to determine biocriteria within tidally-influenced segments. Ideally, any derived biocriteria would have broad spatial applicability.

RESULTS

Due to varying amounts of sampling effort among these studies, the following spatial comparisons of water quality, water chemistry, and biological communities are limited to summer index periods only, as sampling efforts were most uniform during this season. Surface water quality and chemistry measurements are compared to 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.

Physical Properties

Surface measurements of routine Field parameters (Table 1) are displayed in their MDS configurations in Fig. 4. While the ANOSIM test revealed that there were significant differences among the physical characteristics of these different studies (Global R = 0.086, $p < 0.007$), there is a great degree of overlap that cuts across any latitudinal gradient along the coast (Fig. 5a). The between-study pair-wise comparisons revealed that the greatest degree of differences in surface water collections were found between the Lower Coast Study by Harper and Landry and the studies on the upper coast of both the UAA (which included the most geographic northern tidal locations of Lost River and Cow Bayou; R = 0.933, $p < 0.001$) and the collections by TCEQ (including numerous tidal streams around the Galveston Bay area; R = 0.919, $p < 0.001$). These upper-coast / lower-coast distinctions were not consistent though, as the Mission-Aransas Study (MA) was statistically similar to all of the studies on the upper coast. In each case, the parameter most influential in separating out the groups of stations within each of these studies was salinity (Fig. 5b). A general gradient of lowest salinities in the upper coast stations of Halls Bayou, Lost River, and Cow Bayou upper coast to the highest salinities in tidal sections of the Arroyo Colorado and Rio Grande Tidal on the lower coast is quite evident in Fig. 6. Temperature and pH readings were much less influential in the MDS configuration, as were measures of dissolved oxygen concentrations (recorded as either mg/L or percent saturation values, see Fig. 7 a-c). While all of the data used for this particular configuration was collected during the summer season, and despite low dissolved oxygen conditions being evident even in the surface waters, mean dissolved oxygen readings were generally above the threshold value for tidal streams with a High Aquatic Life Use designation. Mean dissolved oxygen readings ranging from a supersaturated high of 15.23 mg/L (± 3.77 mg/L) in the Arroyo Colorado to a low of 4.77 mg/L (±1.08 mg/L) in Cedar Lakes (see Fig. 7).

Chemical Properties

Water chemistry measurements (Table 2) were not collected from either the LCS, WQS, or NTS studies, therefore the analysis of Conventional parameters include only the recent MA study, the historical TCEQ datasets, and the initial UAA studies. Due to a wide range of effort levels in the collection of Conventional parameters among these studies, only Ammonia, Orthophosphate, Total Phosphorus, and Total Suspended Solids were used for this analysis. Despite this shortcoming, these parameters represent an effective suite of water quality indicators. These parameters are summarized by study in their MDS configurations in Figure 8. Bottom water chemistry was not markedly different among the majority of the tidal streams, save for Texas City Pump Canal and the Mission River. All other streams clustered in a relatively small area within the chemical constituent-based MDS. The ANOSIM procedure revealed a significant difference among the studies (Global R = 0.389, $p < 0.001$), with the present Mission-Aransas study being the most unique in terms of surface water chemistry. As was the case with the physical properties, the overall influence of the increased salinities on the Mission River (as recorded by Total Suspended Solids) was most influential in separating out specific tidal streams (Fig. 8b). Nutrient loadings, as measured by Ammonia and Orthophosphate concentrations, showed that the high nutrient levels encountered in the Aransas River were generally similar to the elevated concentrations of both of these constituents encountered in the Texas City Pump Canal and the Highland Bayou Diversion Canal (Fig. 9a and 9b).

Nekton Communities – Near-shore Seine Collections

As detailed in Tolan (2008), the level of effort in the seine collections differed greatly amongst the various studies, especially within the equipment used in the different streams. Collections for the TCEQ studies utilized a 15 X 4 foot straight seine with either 0.125 inch square mesh or 0.187 inch stretch mesh, and five replicate hauls of 25 linear feet pooled into a total catch per 125 feet of shoreline. The gear used for the WQS study was the most variable, with either a 15 X 5 foot, 0.187 inch mesh straight seine or a 30 X 6 foot, 0.125 inch mesh bag seine (6 X 6 foot bag located in the middle of the net) used. In this effort, 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 utilized both a 30 X 8 foot straight seine with 0.187 square inch mesh, and a 10 X 6 foot straight seine with 0.187 inch mesh. In either case, seine pulls were repeated until a linear distance of 125 feet of shoreline had been covered. In the Lower Coast Studies, Harper and Landry utilized a 20 foot long bag seine with 0.25 inch bar mesh wings and a 0.125 inch bar mesh in the 4 foot X 4 foot X 4 foot bag. Their efforts consisted of three replicate seine hauls of 25 linear feet each. Sampling by TPWD in the Lower Coast followed the gear specifications outlined in Martinez-Andrade and Fisher (2010).

The MDS configuration of the summer season seine collections from each study is shown in Fig. 10a. Similar to the MDS configuration of the Physical properties, this community-based analysis again showed a degree of overlap among the geographic locations of the studies (Fig. 6), with the underlying salinity gradient differences also evident in the biotic collections. The R values of the ANOSIM test confirmed statistical differences, with R statistics ranging from a low of 0.361 comparing the WQS collections to the TPWD Studies on the Lower Coast, to a high of R = 0.881 when comparing the MA collections to the Harper and Landry work on the Lower Coast (Fig. 11). Despite the underlying salinity differences, very similar nekton communities were found within each tidal stream. Only a relatively few number of taxa comprised the vast majority of individuals, with bay anchovy, grass shrimp, Gulf menhaden, brown shrimp, white shrimp, and silversides (a mixture of *Menidia spp.* and *Membras martinica*) dominating the catches from nearly every location (Table 4). While the relative proportions of these taxa changed in response to the salinity conditions encountered, each consistently made up the majority of the biota collected with the seines.

As pointed out in Tolan (2008), the potential for systematic bias as the result of the different sampling protocols studies is again recognized in the current analysis, as these biases look to be generally confirmed by a greater degree of overlap of the MA and UAA means plot shown in Fig 11. These two sets of collections were the most uniform in terms of their gears and protocols, as well as personnel, and these two sets of collections were the most alike in terms of their respective communities. While comprised of mainly the same sets of taxa, the TCEQ studies tended to over-represent taxa with high affinities for structured habitat (see Tolan, 2008), whereas the UAA and WQS studies tended to over-represent the pelagic components of the nekton community structure. The Lower Coast Studies also had a high proportion of their nekton communities represented by the more pelagic members (i.e., bay anchovy for the Harper and Landry works, see Table 3), although the finescale menhaden replaced the Gulf menhaden as the most abundant clupeid found in the TPWD Special Studies along the lower coast.

Taxonomic diversity and distinctness tests can be used to account for these systematic biases among the different studies, because one of the qualities of these diversity measures is that they are sample-size independent. 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. Using the species lists from the six different studies under consideration as the master list, a total of 179 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 12a displays the funnel plot for the seine collections, catering for all sublist sizes up to 150 species. The simulated 95% probability limits, based on 999 random selections for each sublist size up to 150, is also shown. Mean taxonomic distinctness is relatively constant at sample diversities greater than 35 taxa, and this diversity level equates to class and order level differences. The limits become increasingly wide as sample diversity decreases, reducing the likelihood of being able to detect a change in distinctness in species-poor collections.

From Fig. 12a, systematic biases among the studies uncovered in the MDS configurations are still evident, as the more uniform sampling strategies used for the Mission-Aransas study and the original UAA work tended to produce clusters of stations more closely together. The lowest degree of taxonomic diversity was recorded in the WQS study, although the only sampling stream to have a mean taxonomic diversity value outside the 95% probability limit were collections on Oyster Bayou from the TCEQ studies. Seine collections from the most recent efforts on the Mission and Aransas Rivers were generally near the theoretical mean, with overall diversity slightly higher within the Mission River. In terms of variation of taxonomic diversity, Mission River was significantly higher than expected (Fig. 12b), and this may be a reflection of the dramatically higher salinity conditions that were encountered on this tidal segment. Recalling from Fig. 8, salinities on the Mission River were the most variable, going from nearly fresh to hypersaline over the course of this study. This high degree of taxonomic variability is the result of the dominance by bay anchovy abundance relative to the remainder of the taxa collected with this gear.

Nekton Communities – Mid-channel Trawl Collections

In terms of the equipment used amongst the studies, the efforts in the trawl collections were somewhat more uniform. The TCEQ studies utilized a 10 foot otter trawl with 1 inch mesh in the wings and 0.25 inch mesh in the cod end. Four, 5 minute replicate trawls were made, and the total catch for all replicates were pooled by station. The WQS study also used a 10 foot trawl with 1 inch mesh in the wings, although the cod end of the net was fitted with a 0.2 inch insert mesh sock. The WQS study conducted three replicate 5 minute trawls at each station. Nekton from each 5 minute trawl was pooled and reported as total catch. Both the NTS and UAA surveys each used a 10 foot otter trawl with 1 inch mesh in the wings and a 0.2 inch mesh sock (insert) in the cod end, with three 5 minute replicate trawls pooled for a the total catch per station measure. The Lower Coast Study by Landry and Harper utilized a 20 foot otter trawl with 0.75 inch mesh in the wings and a 0.25 inch mesh cod end liner for three replicate tows of 10 minute bottom time each. For the present study, these data were further pooled by station and standardized to a total catch-per-unit 5 minute tow, to allow more direct comparisons with previous works. Trawl sampling by TPWD on the Lower Coast followed the protocols outlined in Martinez-Andrade and Fisher (2010).

The MDS configuration of the otter trawl collections are presented in Fig. 13a. The nekton communities recorded by this gear also confirmed the underlying biases of the different sampling protocols, as Fig. 13b is essentially divided between the UAA and MA collections on the right half of the graph, and all other collections on the left half of the graph. Unlike the MDS configuration of the seines, the community-based analysis of the otter trawls showed that salinity was generally less important in structuring the nekton communities across studies. Within a common collection of streams, the same communities were found across widely differing salinity gradients (i.e., Cedar Lakes, Oyster Bayou, and Lost River are statistically similar over an order of magnitude difference in mean salinity, see Fig. 13b). Standardizing the differences in total catch numbers of individuals by their relative percentages (Table 4), the total numbers of taxa encountered in each study was generally similar. Most of the studies encountered between 16 and 23 unique taxa with the otter trawls, although the Lower Coast Studies by TPWD encountered a total of 34 taxa. Many of the taxa exclusive to the lower coast that led to the significant differences amongst the assemblages (ranging from a low of $R = 0.456$, $p < 0.001$, LC – TWPD compared to TCEQ; to a high of $R = 0.95$, $p < 0.001$, LC – HL compared to the MA work) were the more tropical species indicative of the biogeographical shift from temperate to the tropical fauna of the southern Gulf of Mexico (e.g., lesser blue crab, common snook, shoal flounder, and jack crevelle, see Table 4). Nekton communities from each study were dominated by only a few taxa, with only ten taxa defining the otter trawl collections regardless of location or underlying salinity gradient. Those included bay anchovy, Gulf menhaden, blue catfish, white shrimp, Atlantic croaker, sand seatrout, brown shrimp, striped mullet, spot, and blue crab. This assemblage of these ten taxa accounted for between 63.2 % and 99.2 % of the individuals encountered in each study. While collecting similar suites of taxa, the gear-based methodological biases outlined earlier are reinforced by the means MDS plot of Fig. 14, clearly separating the UAA and MA works from all other studies.

Average taxonomic diversity was markedly lower on the Mission River in the MA study, when compared to previous works (Fig. 15a), although this level was still within the 95% confidence limits of the theoretical mean for that given number of species. This lower degree of diversity from the Mission River is a reflection of the hypersaline conditions that the persistent drought brought to this system, where bay anchovy and Gulf menhaden vastly outnumbered all other taxa during the summer sampling periods (Table 4). Only Chocolate Bayou, part of the WQS studies on the middle and upper coast, had mean diversities far greater than expected values for a given sample size. These collections had the lowest within-group average similarity values (SIMPER average similarity value = 1.8, see Table 7 - Tolan, 2008), even though the vast majority of the individuals were still part of the ten-most dominant taxa found coast-wide (from Chocolate Bayou; white shrimp, bay anchovy, and sand seatrout). In each study, variation in taxonomic diversity was above the expected theoretical mean (Fig. 15b), and this is a direct reflection of each collection being dominated by only a few taxa, in some cases greatly outnumbering all others, when community structure was measured by the otter trawls. Generally missing from the configurations of taxonomic diversity was a connection between physically degraded water-bodies (e.g., Highland Bayou Diversion Canal, Texas City Pump Canal; see Fig. 8) and a general lowering of observed diversity. The same suite of numerically dominant taxa appears to be ubiquitous along the entire Texas coast.

Spatial Applicability for a Derived Biocriteria

From Fig. 2, the derivation of a biocriteria should ultimately provide information on the ‘ecological health’ of the system under investigation, by incorporating measures of community composition and abundance of the numerous trophic levels recorded in the biota with information describing the physical and chemical components of the habitats in which they live. The primary task of the UAA studies (Contreras and Whisenant, 2007, Tolan et al., 2007) was to determine which of these measured components of ecosystem health (physical, chemical, or biological, or some combinations among those) effectively identify differences between reference and study streams. In that context, the choice of a reference stream is critical, because historically, comparisons of ecological conditions within water-bodies have typically been evaluated against a similar reference water-body with minimal impacts. As few places along the Texas coast are unaffected by anthropogenic disturbances, true reference conditions are generally unattainable. The multivariate techniques outlined previously allows for these comparisons to be made without relying heavily on the choice of a reference stream, as various locales can be compared amongst themselves and any “outliers” within the multidimensional space can be identified as either prospective ‘pristine’ of ‘impaired’ systems (Fig. 3).

The UAA studies generally found little difference existed between the reference streams and any of the other study streams (upper coast UAA, Contreras and Whisenant, 2007; middle coast UAA, Tolan et al., 2007), with community-based indicators of ecosystem health generally involving upstream – downstream gradients that were primarily driven by salinity structure. These salinity gradient conditions cut across all trophic levels of ecologic integrity, with similar patterns replicated by the nekton, the benthic infauna, and the aquatic invertebrates. What was not seen was any clear separation of a reference condition and any of the 'impaired' or 'impacted' water-bodies. As noted in Tolan et al. (2007), one of the main drawbacks to the pair-wise comparison approach (impacted vs. reference) is that with a low number of streams available for comparison, the actual differences between conditions must be very large to show any clear difference. Therefore, a second study utilizing historical data sets from a number of tidal streams encompassing a sizable part of the Texas coast was undertaken (Tolan, 2008), and these data were analyzing with this standardized multivariate methodology in the hopes of uncovering a robust biocriteria that had broad spatial applicability.

These same methods were applied to the nekton communities recorded from a much larger spatial and temporal scale than those that were recorded during the UAA studies. Despite the sampling locations ranging from the northern-most locations on Cow Bayou (Sabine Lake tributary, see Fig. 1) to the tidal sections of the Nueces River to the south, the communities collected with both the seines and otter trawls were still quite similar, and more importantly, quite consistent, regardless of any "impairments" associated with an individual stream. This study showed that the communities at nearly all tidal streams were dominated by a limited number of common taxa, and these taxa each displayed tremendous euryhaline / physiological abilities (Gunter, 1961, Patillo et al., 1997) which enabled them to adapt to a wide variety of salinity, temperature, and dissolved oxygen level conditions. One important point of this assessment, as noted by Tolan (2008), was that sampling methodologies biases appeared to play a larger role in the structuring of the community compositions for some gears than did either the physical of chemical components of ecosystem health. As such, the end result of the Assessment Methodology, as shown in Fig. 2, still lacked the critical Index Development step. This step, which is predicated on 'candidate taxa' that are sensitive to changes in the sometimes dramatic fluctuations in the chemical or physical conditions found within tidally influenced ecosystems, is essential if a biocriteria is to be formulated.

The present study extended the spatial, as well as the temporal range of the collections to encompass the entire Texas coast, spanning multiple decades from the 1980's through 2009. The historical collections used in Tolan (2008) were merged with additional middle coast collections (Mission and Aransas River tidal study, Tolan et al., 2011) and lower coast sampling efforts (Arroyo Colorado and Rio Grande Tidal, see Descriptions of Study Streams) in order to help uncover any potential 'candidate taxa' from which a spatially applicable biocriteria could be formulated. As outlined in the Results section, both gears recorded nekton communities that were heavily dominated by just a few common taxa, and these same taxa were ubiquitous across all studies despite any of the individual gear-biases or methodological differences. In order to standardize these taxa abundances across the different suites of studies, their abundance levels within each sample was re-scaled as the numerical percentage of the total sample (ranging from 0 = absent, to 100 = only taxa collected), and then these percentages were regressed against the dominant physical variables used to differentiate amongst the collections.

Figure 16 shows the general trends in the abundance of the six-most common nekton recorded with the seines (bay anchovy, grass shrimp, Gulf menhaden, brown shrimp, white shrimp, and silversides) and summer-time surface water temperatures across the entire Texas coast. While each taxa shows a general increase in abundance with increased surface water temperatures, the explanatory power of any of these regression lines is extremely low (R^2 values << 0.05). More importantly, the scatter of the individual sample points around the trend lines point to the high degree of variability in the nekton collections, and this level of variability is common to each of the most abundant taxa. As an example, at 32^o C, bay anchovy, Gulf menhaden, and white shrimp were each as likely to make up 0% of a sample as they are to comprise 100% of a sample (see Fig. 16). What is not seen in any of the regression plots are any abrupt increases or declines which would signal a particular physiological limit or an environmentally induced inflection point that could have a meaningful interpretation in the context of the Index Development step (Fig. 2). Similar levels of variability and generally increasing trends with increased dissolved oxygen levels were also seen for these same taxa (Fig. 17), although Gulf menhaden were noted to be most abundant in the lowest DO concentrations and decline dramatically after DO concentrations exceeded 12 mg/L. This pattern corroborates the field observations seen on both the UAA studies and the MA study, where those researchers noted high abundance levels of Gulf menhaden in tidal waters with low surface-water dissolved oxygen concentrations. The patterns for these same six taxa and salinity are shown in Fig. 18. For this physical parameter, the patterns were more mixed, although the level of variability was comparable to that seen for both temperature and dissolved oxygen. Across salinity levels that ranged from completely fresh to hypersaline, both bay and anchovy and grass shrimp abundances were generally unaffected by salinity; Gulf menhaden showed an inverse relationship with salinity (this taxa was generally uncommon in salinities above 25); whereas brown shrimp, white shrimp, and silversides displayed a generally increasing trend in abundance with increasing salinity (see Fig. 18).

The six taxa most abundant in the otter trawls (bay anchovy, Gulf menhaden, blue catfish, white shrimp, Atlantic croaker, and sand seatrout) were also normalized by sample and their abundance percentages were similarly regressed on the environmental drivers. Compared to surface-waters, the range of bottom-water temperatures across the summer period were generally similar (primarily between 25^{o}C and 34^{o}C), although the scale in Fig. 19 has been expanded to account for the few extreme observations encountered in the trawl collections. While most taxa tended to decrease in abundance as temperatures increased, sand seatrout abundances were unrelated to temperature, whereas bay anchovy increased in abundance as temperatures warmed. Dissolved oxygen concentrations were less variable in the bottom-waters, ranging from anoxic condition to 14 mg/L, which was about half of the upper end of the DO concentrations seen in the surface-water collections (Fig. 20). The trends in the taxa common to both gears across the DO gradient were similar for both Gulf menhaden and white shrimp, although bay anchovies tended to follow the pattern of Gulf menhaden (highest abundance amounts found in low DO concentration bottom-waters) when recorded with otter trawls. Blue catfish tended in increase in abundance with higher DO levels, and both Atlantic croaker and sand seatrout were generally unresponsive to this environmental driver. Like the patterns seen in the seine collections, low DO thresholds (4 mg/L or lower) did not necessarily equate to reduced abundance levels in the most common taxa, and some taxa were equally abundant in hypoxic and sometime anoxic bottom-waters (bay anchovy and Gulf menhaden; see Fig. 20) as they were in fully saturated bottom-waters. Salinity patterns for the otter trawls are shown in Fig. 21. Trawl sampling-based relative percentages were the most variable for bay anchovy, Gulf menhaden, and Atlantic croaker, with their percentages of the total collections ranging the full spectrum across salinities as varied as from 0 parts-per-thousand to 45 parts-per-thousand. Only blue catfish was noted as exhibiting a physiological threshold, with abundances of this taxa declining dramatically after salinities exceeded 10 (although a single sample did record low levels of blue catfish abundances in bottom-waters exceeding 20, see Fig. 21).

DISCUSSION

Assessing the factors which influence the diversity of taxa and their associated abundance levels within an assemblage has long been a common theme in studies of community ecology (Sosa-Lopez and Mouillot, 2007). These assessments are most robust when the effect of sampling scales on the observed community structure patterns are taken into account (Wiens, 1989; Levin, 1992). While the topic of scale has received explicit attention in some freshwater (Kennard et al., 2007; Wilson and Xenopoulos, 2008; Palmer, 2009) and marine fish studies (Rose and Leggett, 1990; Pease, 1999; Nunez-Lara et al., 2005), studies on fish communities within estuaries, especially those residing in the tidally influenced portions of the estuary, less often deal explicitly with this issue of scale (although see Bacheler (2009) and Nicholas et al.(2010) for more recent examples of estuarine studies addressing the confounding effects of scale). Many factors have been proposed as the driver responsible for determining estuarine nekton assemblage structure and these occur at vastly different scales and in a variety of ways: from the global scale at which species richness and abundance may be strongly influenced by latitudinal gradients, estuary size, habitat diversity, and estuarine mouth configuration (Hillebrand, 2004; Harrison and Whitfield, 2006; Nicolas et al., 2010); to a more regional scale where factors such as salinity, temperature (e.g., seasonality), habitat type, or river flow may have a more pronounced impact on distribution and abundance (Marshall and Elliott, 1998; Tolan et al, 2007; Vasconcelos et al., 2010; França et al., 2011).

The initial task of the UAA studies, where the multivariate, community-based Assessment Methodology was first employed was to identify which environmental drivers (or differences in the physical, chemical, or biological components of ecosystem health) could be shown to differentiate reference streams and "impacted" streams at disparate locations along the Texas coast. While these studies were limited both in their spatial and temporal scales, they initially served as the test-cases for the implementation of the assessment methodology. Based on the results of those earliest studies, clear differences were lacking between streams classified as either Exceptional or High (Tolan et al., 2007), and this lack of distinction between those designations cut across numerous levels of trophic structure. This seemingly negative result served to validate the assessment methodology as being internally coherent, at least at the local scale, because the same environmental driver that could be used to differentiate tidal streams locations (namely, salinity) was the common driver shaping community structure. As previously stated, the main 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 divergence. The present study furthers this task of determining whether differences in the physical, chemical, or biological components of "ecosystem health" can be found among tidally influenced streams with varying degrees of freshwater inflows, because the issue of scale is now implicitly addressed. By comparing different suites of study locations spanning the length of the Texas coastline, and sampling efforts that spanned environmental conditions across multiple decades, the multivariate Assessment Methodology is robust enough to uncover community structure patterns at much larger scales. As previous authors have noted, there is no single correct scale at which to quantify the spatial distribution of populations and some have suggested that habitat use must be examined on multiple scales (Wiens, 1989; Levin,1992).

Water Quality Assessments

The ANOSIM tests within the Assessment Methodology revealed that there were significant differences among surface-water physical characteristics seen in the different studies (Fig. 6), although the high degree of overlap among the individual stations discounted any large-scale latitudinal gradient along the coast.

While pair-wise comparisons revealed that the greatest degree of differences in surface water collections were found between the Lower Coast Study by Harper and Landry and the UAA and TCEQ studies on the upper coast, these distinctions did not appear to be latitudinally consistent. As an example, the Mission-Aransas Study (MA) was statistically similar to all of the studies on the upper coast, even though the two rivers for this study are located geographically closer to the Nueces, Arroyo Colorado, and the Rio Grande Tidal than to any of the tidal streams on the upper Texas coast (see Fig 1). The important distinction within the ANOSIM tests of the physical characteristic was that when differences could be identified, the parameter most influential in separating out the groups of stations was universally salinity (Fig. 5b). Taken at a large enough spatial scale, a general gradient of lower salinities within the upper coast stations to higher salinities on the lower coast stations was evident, yet within a regional scale of an individual-studies (WQS Study along the middle Texas coast) to a limited local scale (TCEQ studies centered around Galveston Bay), this salinity trend is interrupted by the high degree of variability within different tidal segments (see Table 1). This overarching role of salinity (and secondarily, turbidity; see Akin et al. 2005 and Wieski et al., 2010) in structuring the available habitats within estuaries has been commonly reported (Jassby et al., 1995; Nicolas et al., 2010; Piazza and La Peyre (2011), and was one of the most important factors identified by one of the largest-scale assessments of tidally influenced waters ever undertaken (European Union's Marine Strategy Directive; see McQuatters-Gollop 2009). The other physical parameters of temperature, dissolved oxygen concentrations, and pH readings were each far less influential in configuring the stations amongst the studies, although this could be attributed to the limited temporal scale of the present study (the common summer season being the only time period under consideration due to the non-uniformity of collections across studies).

The spatial and temporal coverage of water chemistry properties (either surface- of bottom-water collections) 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. 8). Tidal streams generally considered as "impaired" were the systems that were identified by this analysis as being most unique , As an example, excess nutrient loads within Texas City Pump Canal and Highland Bayou Diversionary Canal, lead to these systems generally falling outside the main MDS grouping. Mission River was also identified as being unique, but it's location within the chemistry-based configuration was directly tied to the extreme salinities (as measured by the high TSS values) that were found in this system as a result of drought conditions. Again, the overarching role of salinity in defining measures of 'ecological health' is again reinforced (Martino and Able, 2003; Akin et al., 2005).

Nekton Assemblages

Based on the total nekton collections shown in both Fig. 10 (seine collections) and Fig. 13 (otter trawl collections), salinity again appears to play the underlying role in structuring community compositions. Yet, even across dramatic salinity differences, the same handful of taxa dominate 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). These families regularly exploit the wide variety of available habitats present within tidal systems, even across the climate-induced bias amongst the studies that was outlined by Tolan (2008). Missing from either Fig. 10 or Fig. 13 is a connection between any of the supposed "impaired" water quality streams to a subsequent "impaired" biological community. 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). Although sampling biases among stthe studies was quite evident (e.g., white shrimp, Atlantic croaker, and spot in the TCEQ studies; Gulf menhaden and bay anchovy in the UAA and MA studies), the same general communities were recorded from each tidal system, regardless of any level of impairment.

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 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. The notion of scale is also relevant in addressing the MDS configurations of community composition, as it is thought that large-scale (kilometers) patterns in the distribution of organisms result primarily from species responses to their physical environment (Remmert, 1983). Abiotic factors may set up the community framework, while biotic interactions refine species distribution patterns within this structure. At the scale of the community, salinity appears to structure nekton diversity and abundance levels, whereas at the level of the individual (i.e., species), salinity does not have as large of an effect (see Figs. 18 and 21) because of their physiological tolerances previously outlined. Given the extreme euryhaline / physiological abilities found in many of the species that comprise the biologic communities found within tidally influenced systems, few estuarine taxa earn a true description of "sensitive" (See Fig. 2C).

The application of this bioassessment, or more explicitly the derivation of a particular biocriteria metric with broad spatial applicability, expands upon the classical population ecology theory of stability and climax community structure, which was first introduced in the field of terrestrial ecology by Clements (1936). The general underlying assumption for this metric calculation is that communities can approach a condition of higher biological integrity when they are not impaired by disturbance, and in its implementation under the IBI approach, it is implies that disturbance is linked with human activities (Clarke and Warwick, 2001). However, tidal streams are not isolated systems with stable climax communities (Caswell, 1976), and a number of studies indicate that the benthic macrofaunal communities of these areas are composed of meta-populations of colonizing generalists (Livingston et al., 1976; Ross et al., 1989; Glancy et al., 2003) and the fish community of these same areas are comprised of taxa that are ubiquitous to estuaries along the entire Gulf coast. The bioassessment approach thus breaks down, at least in terms of the present Methodology as it has been applied to the nekton communities, precisely because the same groups of taxa always make up the "communities" no matter what the environmental conditions happen to be, and the only change in these communities is a change in their relative abundances under differing environmental conditions. For many of the taxa that define Texas tidal stream communities, abundance levels at the individual-scale appear to be largely disconnected from the major environmental drivers that are currently used to describe 'ecological conditions'. The absence of any meaningful Index Score (see Fig. 2, part C) derived from the nekton communities, especially one which could have broad spatial applicability, should not be viewed as a failure of the Assessment Methodology as a whole, but rather a confirmation of the complexities in selecting indicators to be used in describing the condition of the ecosystem and its parts and subsets. (Busch et al., 2002). Clearly, the results of this study shows that the nekton portions of tidally influenced ecosystems are not an especially sensitive indicator, and that negative outcome does have broad spatial applicability. A successful Index Score development will thus have to be drawn from some other biological subset of the system.

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., at least not when using the nekton community as the indicator.

The assessment methodology used for this study was designed to capture community-level information on the richness and diversity of the tidal stream assemblages, both in terms of the number of species present 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 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. 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.

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Table 1. Field parameters by tidal stream. Color coding of Studies follows Fig.1. 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. Dashed lines (-) indicate parameter not measured.

Tidal Stream	Temp.	(SD)	pH	(SD)	D.O.	(SD)	Specific Conduct.	(SD)	Salinity	(SD)	Secchi Depth	(SD)
▲ Mission	30.97	(0.6)	8.19	(0.2)	5.70	(0.9)	37095.83	(20748.3)	23.96	(14.5)	0.58	(0.1)
▲ Aransas	31.54	(0.6)	8.54	(0.2)	7.27	(0.8)	17409.17	(15531.3)	10.63	(9.9)	0.41	(0.2)
■ 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)
▼ Nueces												
♦ 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 1 (cont.)

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)
○ Arroyo Colorado	30.83	(0.8)	-	-	16.73	(3.2)	-	-	14.67	(8.1)	-	-
○ Rio Grande	30.00	(1.0)	-	-	13.70	(4.3)	-	-	10.17	(10.1)	-	-
- Arroyo Colorado	30.74	(1.6)	-	-	7.46	(1.6)	-	-	4.59	(8.1)	-	-
- Rio Grande	31.55	(4.7)	-	-	7.92	(4.7)	-	-	12.63	(6.6)	-	-

Table 2. Conventional parameters by tidal stream. Color coding of Studies follows Fig.1. 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. Dashed lines (-) indicate parameter not measured.

Tidal Stream	Ammonia	(SD)	Ortho-Phos.	(SD)	Total-Phos.	(SD)	Chl a	(SD)	TSS	(SD)	TOC	(SD)
▲ Mission[1]	0.04	(0.06)	0.02	(0.01)	0.14	(0.07)	-	-	43.51	(35.04)	-	-
▲ Aransas[1]	0.04	(0.03)	0.20	(0.21)	0.49	(0.18)	-	-	44.68	(22.65)	-	-
♦ 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)
● 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)

[1] Chlorophyll a readings were not collected from the Mission and Aransas Rivers because water chemistry analysis was done on bottom-water samples.

Table 3. Relative contribution of each taxa (% of Total, by study) to at least 95 % of the overall community structure as measured by shallow water seines during the summer season. Dashed lines represent contributions of << 1.0 %; empty cells represent taxa not encountered during summer sampling.

Taxa	MA	WQS	TCEQ	UAA	LCS - HL	LCS - TPWD
Bay anchovy	30.44	52.48	15.41	3.39	65.83	3.29
Grass shrimp	14.50	5.40	42.87	1.08	1.26	3.47
Gulf menhaden	14.28	16.06	3.16	89.98	-	4.50
Tidewater silverside	13.55		0.98	0.16	-	4.46
Brown shrimp	4.93		0.50	0.83	2.73	6.05
White shrimp	3.51	19.22	10.93	1.18	3.13	14.98
Sheepshead minnow	3.48	-	3.82	-	-	2.70
Gulf killifish	2.23	-	0.67	-		1.68
Sailfin molly	2.12	0.61	2.86	0.25		
Gulf pipefish	1.67		-	-	-	
Naked goby	1.36	-	-	-	-	-
Striped mullet	1.24	-	-	0.21	-	6.36
Rio Grande cichlid	1.13					
Western mosquitofish	1.05	0.43	6.38	0.90		-
Blue crab	-	-	2.25	0.32	1.03	1.76
Inland silverside	-	2.80	3.37	-	5.01	2.23
Spotted seatrout	-	0.53	-	-		
Spot		0.22	-	-	-	2.96
Spotted sunfish		-	3.62	-		
Scaled sardine			-		9.39	-
Mojarra sp.	-	-	-	-	5.11	1.08
Striped anchovy		-	-		2.24	-
Darter goby			-	-	1.30	
Finescale menhaden						17.23
White mullet		-	-	-	-	7.38
Hardhead catfish	-	-	-		-	5.97
Pinfish	-	-	-	-	-	4.84
Crevalle jack		-	-			2.04
Highfin goby						1.31
Lesser blue crab						1.16
Sum - % Total	95.48	97.75	96.82	98.31	97.03	95.44

Table 4. Relative contribution of each taxa (% of Total, by study) to at least 95 % of the overall community structure as measured by mid-channel otter trawls during the summer season. Dashed lines represent contributions of << 1.0 %; empty cells represent taxa not encountered during summer sampling.

Taxa	MA	WQS	NTS	TCEQ	UAA	LC - HL	LC - TPWD
Bay anchovy	92.82	10.63	2.18	10.25	56.69	2.23	1.44
Gulf menhaden	3.71	-	15.05	0.94	33.04	-	6.78
Blue catfish	1.91	-	18.02	3.59	2.54		-
White shrimp	-	81.29	18.26	53.89	2.57	11.72	22.46
Atlantic croaker	-	3.42	9.65	6.90	-	7.72	12.30
Sand seatrout	-	1.63	1.08	8.99	0.96	2.23	1.16
Brown shrimp	-	-	17.24	3.98	0.70	11.28	1.63
Striped mullet	-	-	4.45	-	-	-	3.63
Hardhead catfish	-	-	3.62	-	-	2.23	2.77
Spot	-	-	1.71	4.21	-	23.29	9.50
Blue crab	-	-	1.31	3.57	-	4.75	8.62
Gizzard shad	-	-	1.28	-	-		-
Silver perch	-	-	0.97	-	-	5.93	2.03
Pinfish		-	0.55	-		0.89	10.42
Silver seatrout						6.68	-
Atlantic cutlassfish						2.97	-
Scaled sardine						2.97	-
Family Macrobrachium	-		-	-	-	2.97	
Bay whiff		-	-	-	-	2.52	1.05
Striped anchovy				-		2.52	-

Table 4 (cont.)

Taxa	MA	WQS	NTS	TCEQ	UAA	LC - HL	LC - TPWD
Mojarra species				-		1.19	2.03
Atlantic moonfish						0.74	-
Gafftopsail catfish		-	-	-	-	0.74	-
Grass shrimp			-	-	-		2.20
Red drum			-		-		1.19
Lesser blue crab							1.15
Common snook							0.99
Shoal flounder							0.69
Channel catfish	-	-			-		0.68
Threadfin shad	-		-	-	-		0.65
Gafftopsail catfish		-	-	-	-	-	0.45
Atlantic threadfin						-	0.44
Bigmouth sleeper							0.42
Fringed flounder							0.34
Crevalle jack							0.32
Sum - % Total	98.44	96.97	95.37	96.32	96.5	95.57	95.34

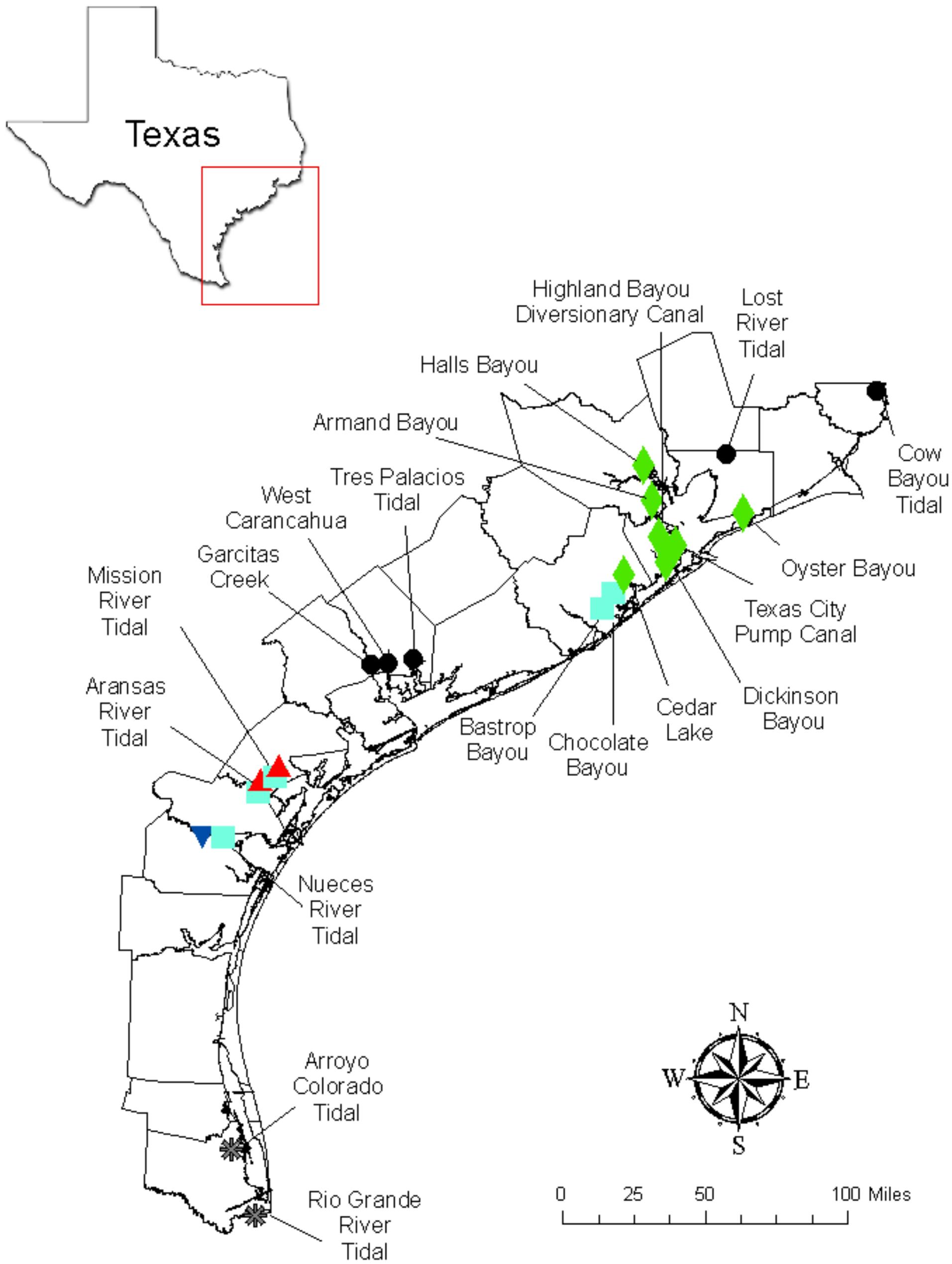


Figure 1. Map of tidal stream locations used for the Coast-wide Assessment Methodology, color-coded by study: red = Mission – Aransas TIDAL2 (MA), light blue = Water Quality Survey (WQS), dark blue = Nueces Trawl Survey (NTS), green = Texas Commission on Environmental Quality - Upper Coast Studies (TCEQ), black = Texas Parks and Wildlife Department - Use Attainability Analysis (UAA), gray = Lower Coast Studies (LCS).

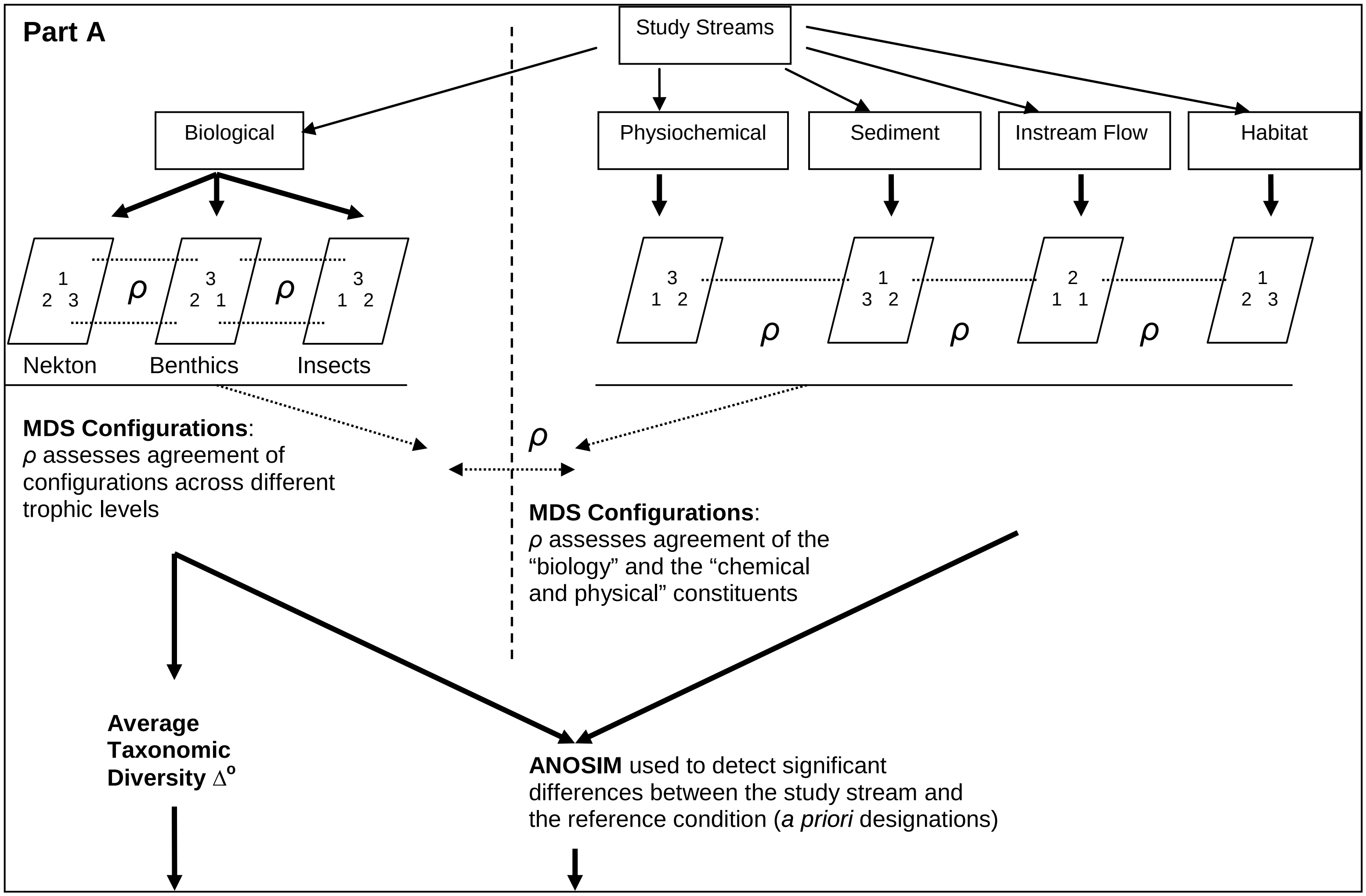


Figure 2. The process for assessing ecosystem health and determining biocriteria in tidally influenced streams.

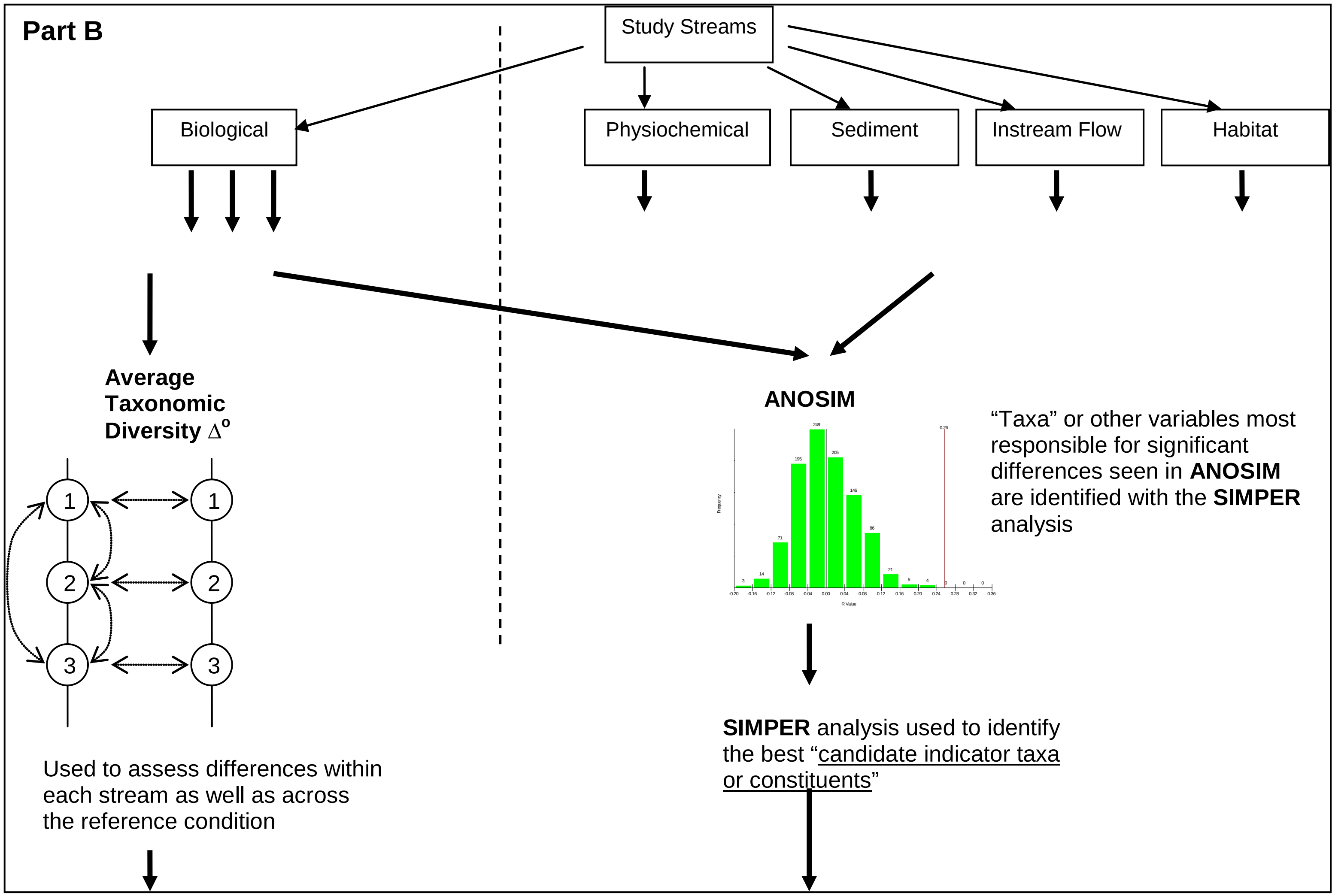


Figure 2. The process for assessing ecosystem health and determining biocriteria in tidal streams (continued).

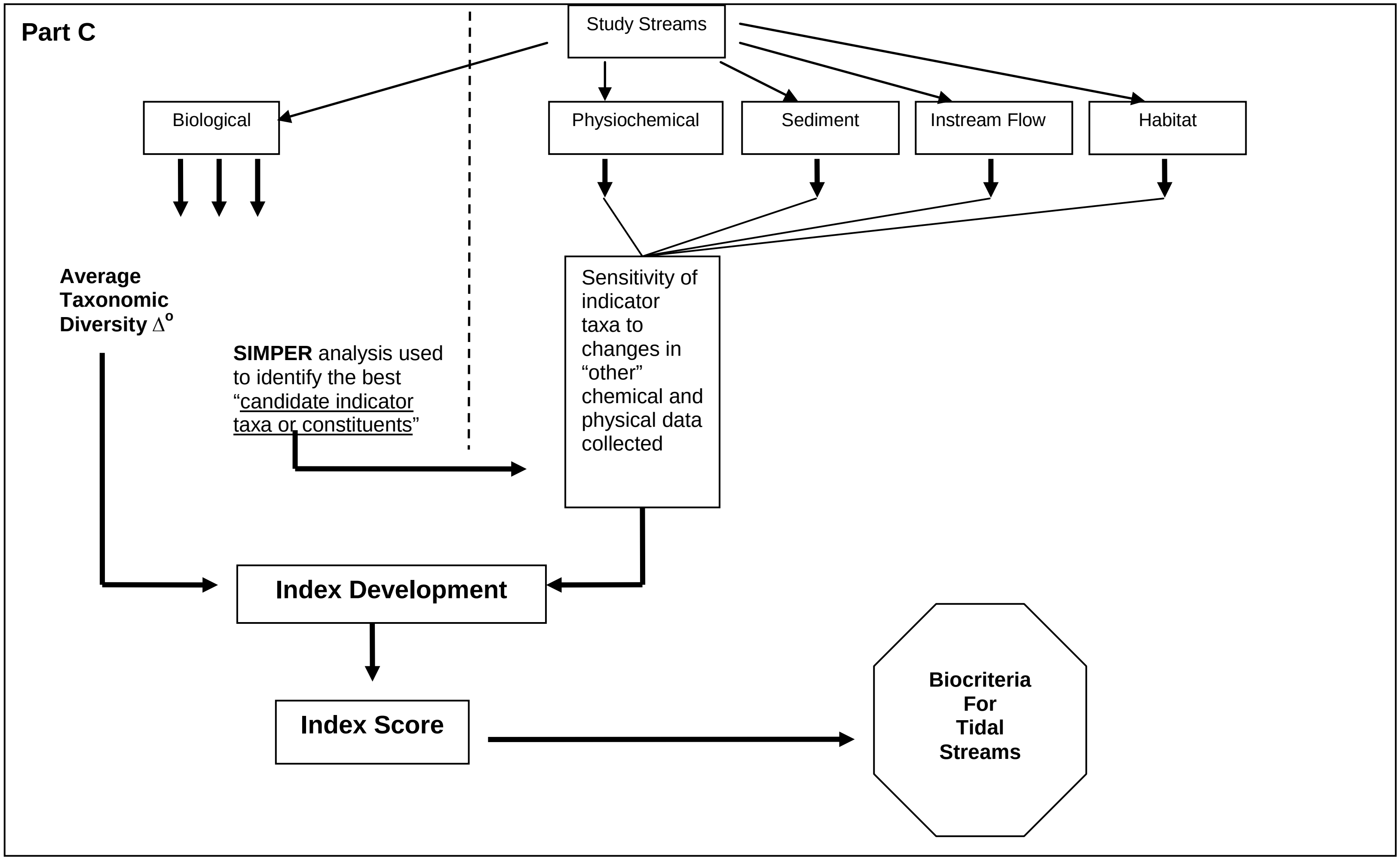


Figure 2. The process for assessing ecosystem health and determining biocriteria in tidal streams (continued).

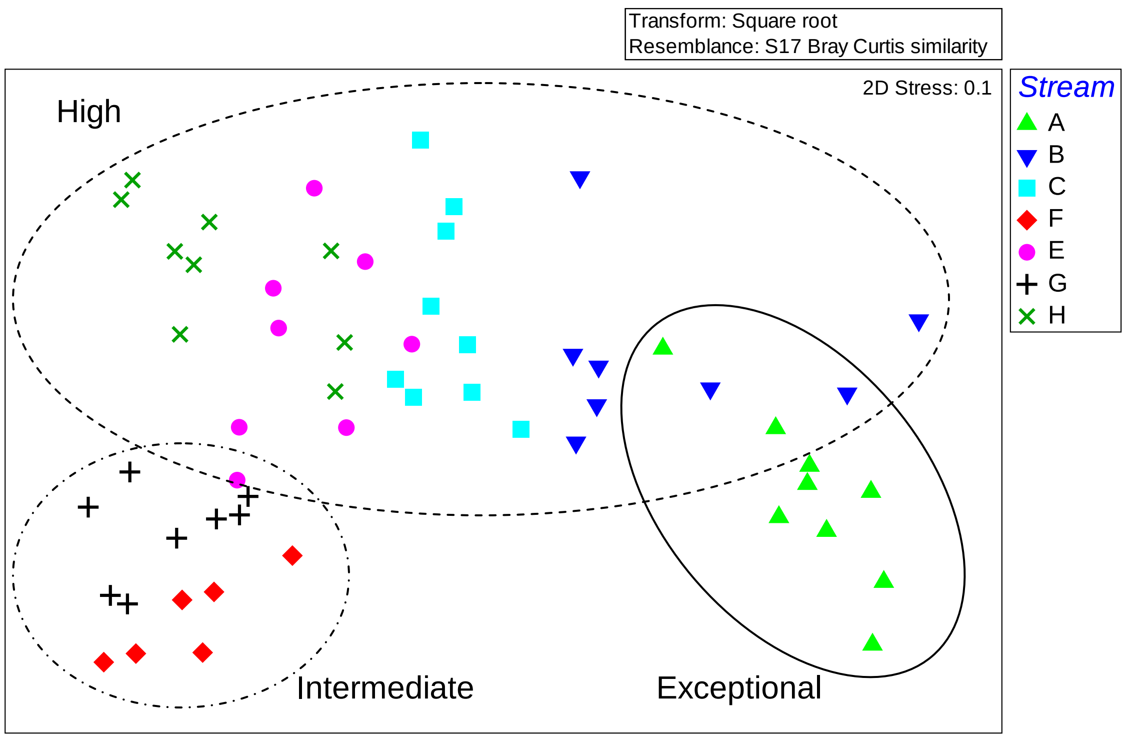


Figure 3. Hypothetical MDS ordination of biological collections from seven tidally influenced coastal stream. Stream A is designated as the Reference Stream. Aquatic Life Use designations as follows: Stream A = Exceptional (enclosed in solid line ellipse); Streams B, C, E, and H = High (enclosed in dashed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

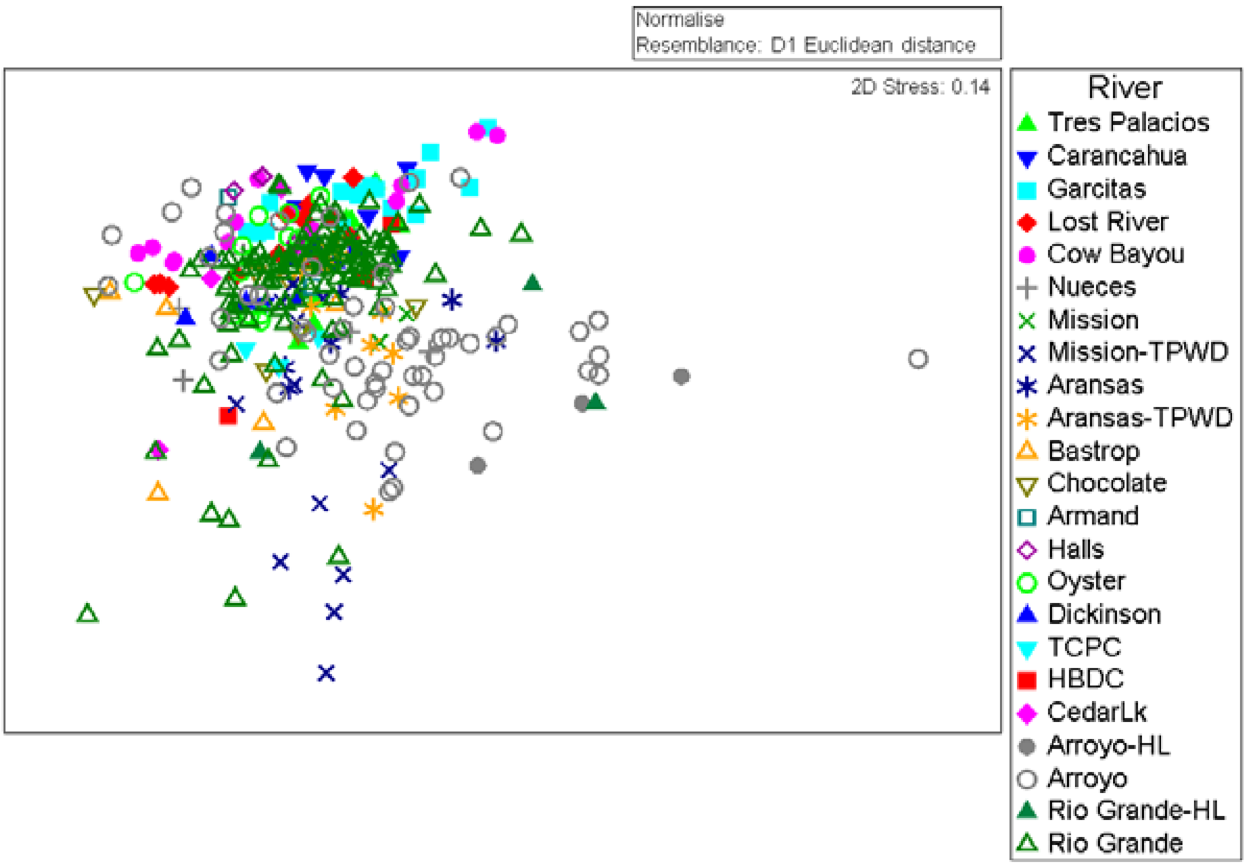


Figure 4. Multidimensional scaling ordination of the tidal stream locations, based on surface measurements of routine Field parameters. Each tidal stream is labeled individually, to provide spatial context to the coast-wide MDS configuration.

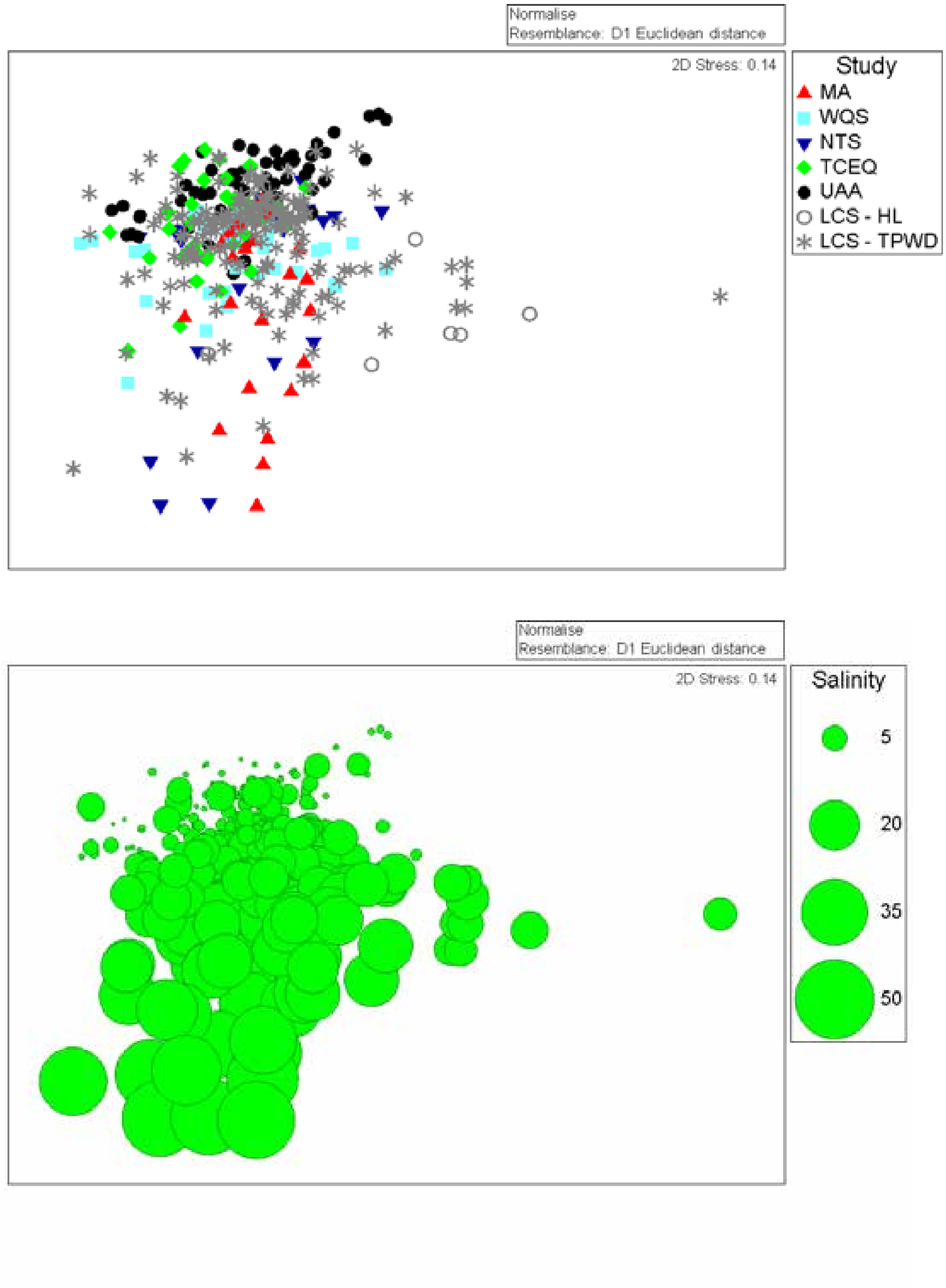


Figure 5. Multidimensional scaling ordination of the tidal stream locations, labeled by study; (A) based on surface measurements of routine Field parameters; and (B) overlaid with individual salinity measurements.

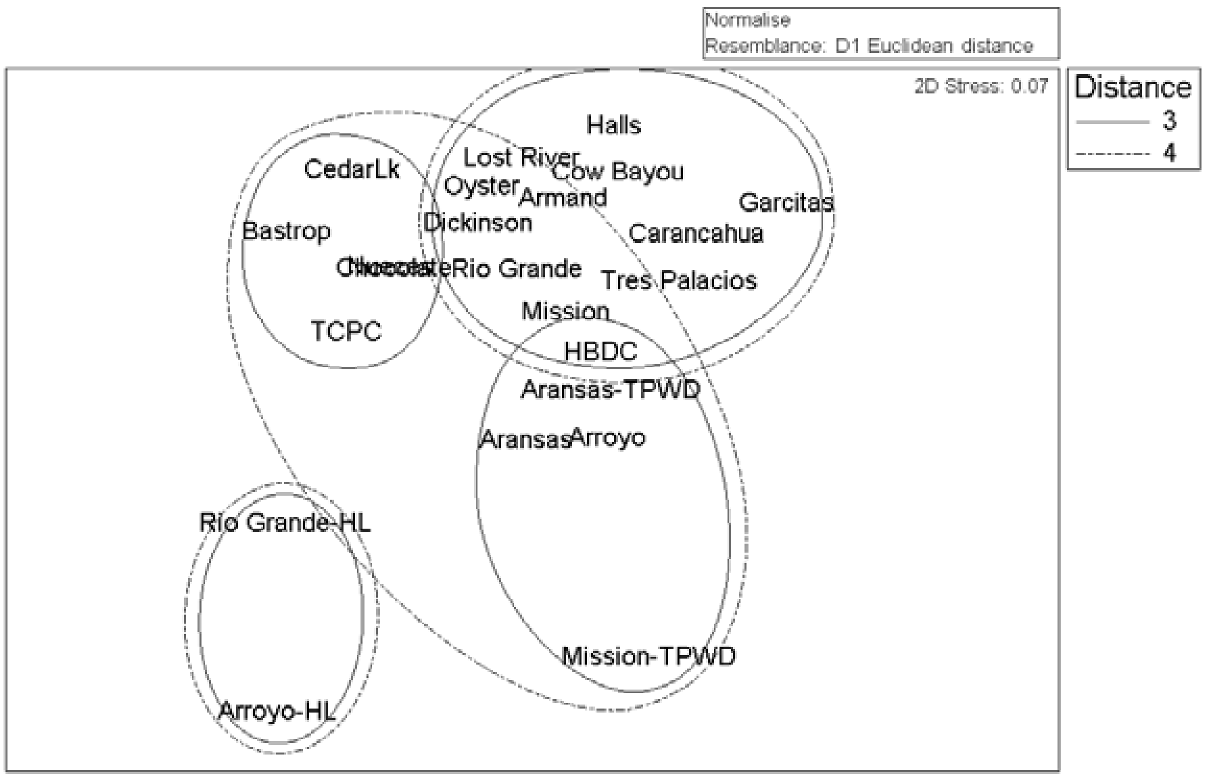


Figure 6. Multidimensional scaling ordination means plot of the tidal streams based on surface measurements of Field parameters. Streams within a common ellipse are not significantly different at the α = 0.1 level (dashed line) and the α = 0.05 level (solid line). Distance based on Euclidean distances of pair-wise similarity measures taken from a complete linkage Cluster Analysis of the complete similarity matrix (not shown).

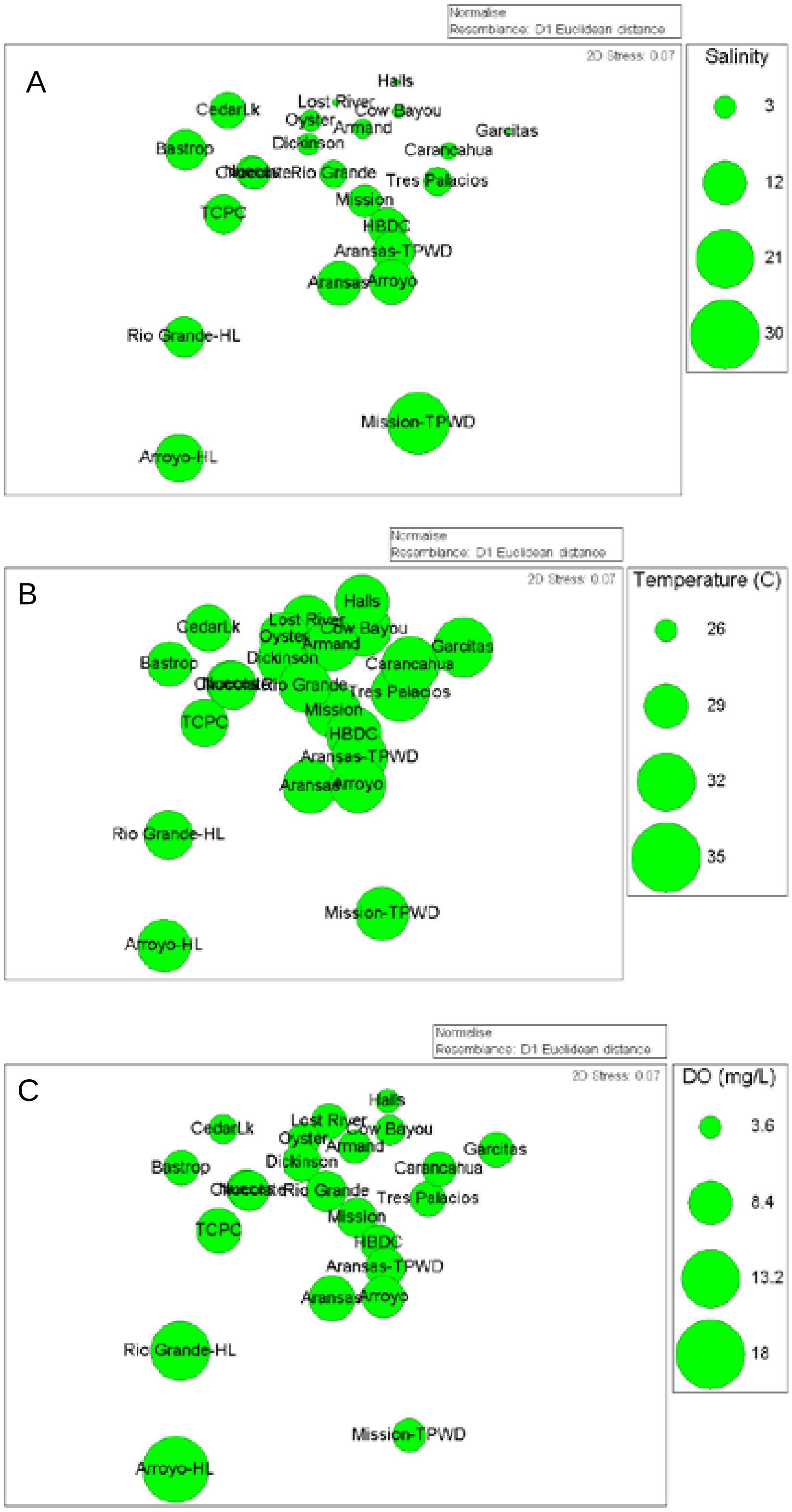


Figure 7. Multidimensional scaling ordination means plot of the tidal streams based on surface measurements of Field parameters. Overlaid onto each plot are the mean salinity (A), temperature (B), and dissolved oxygen concentrations (C) recorded from each tidal stream.

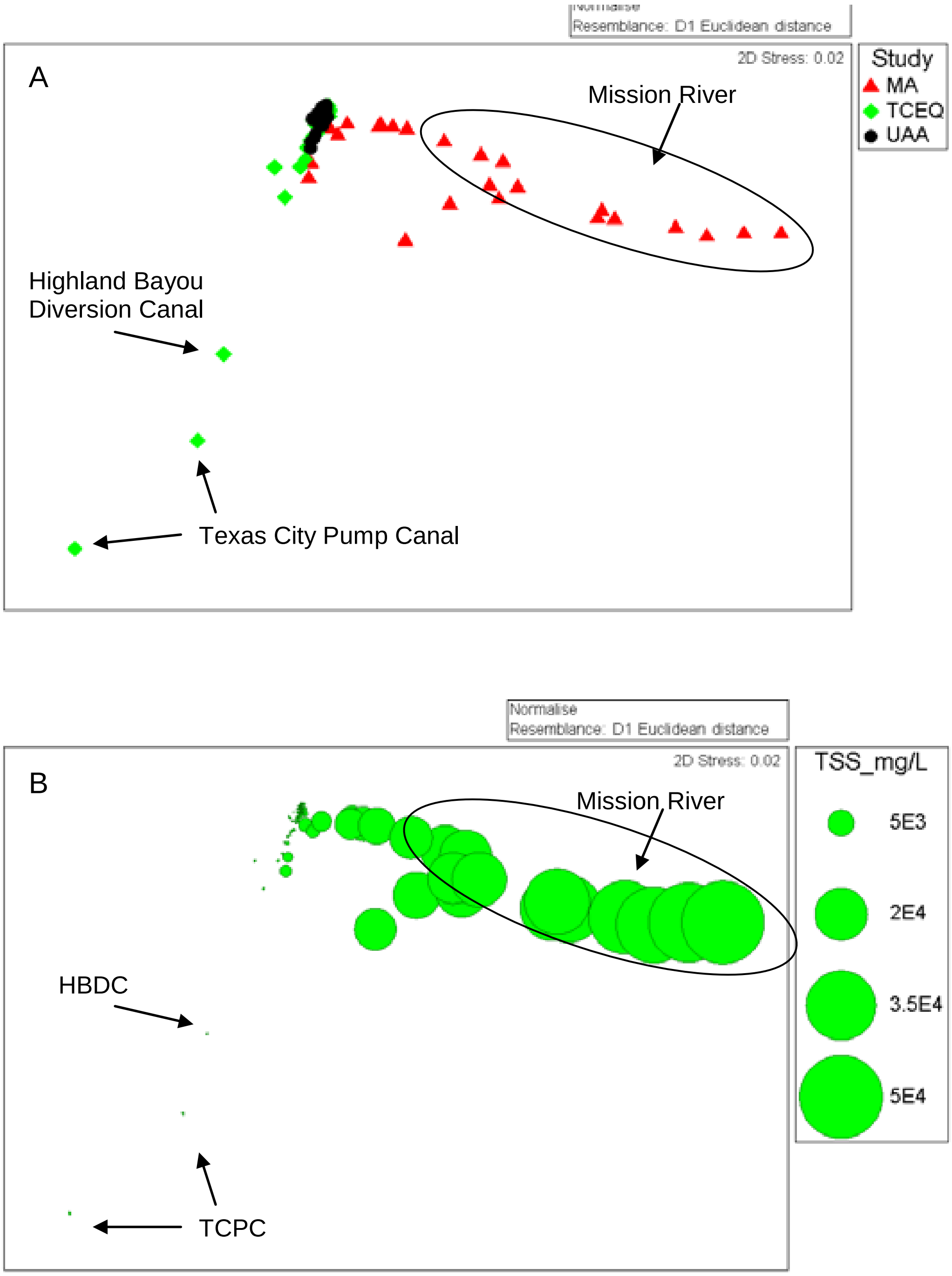
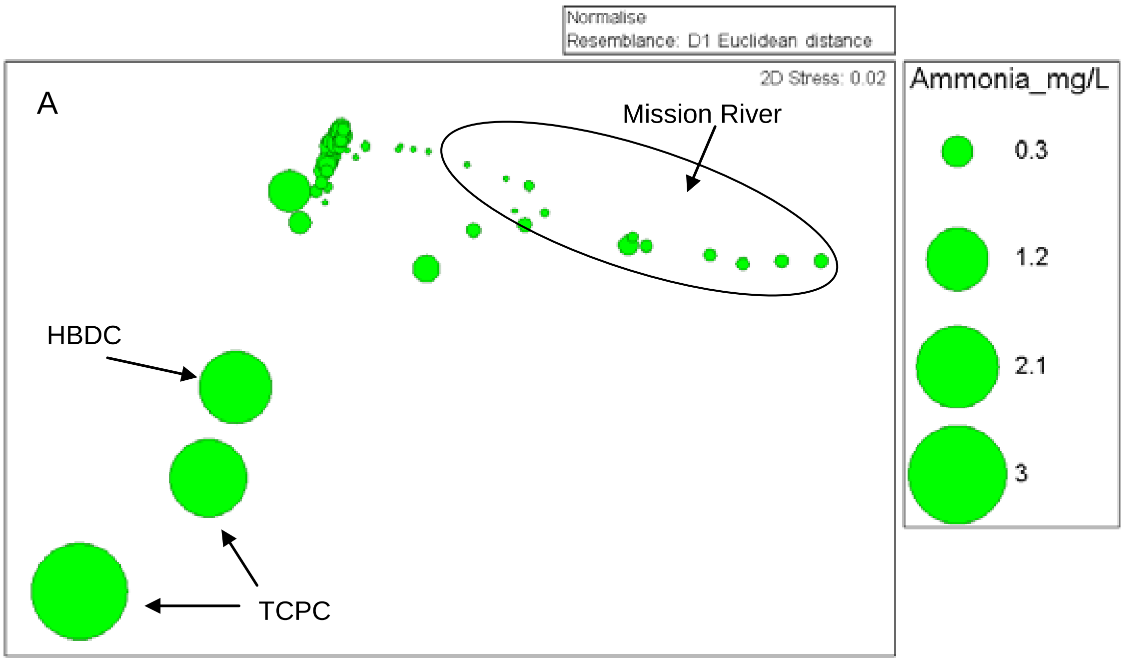


Figure 8. MDS configuration of the stations based on bottom-water collections of Conventional parameters from all studies. A = Stations within Studies configuration (streams discussed in the text individually labeled); B = overlaid with surface-water column Total Suspended Solids concentration. Size of each circle is represented by the scale at the right.



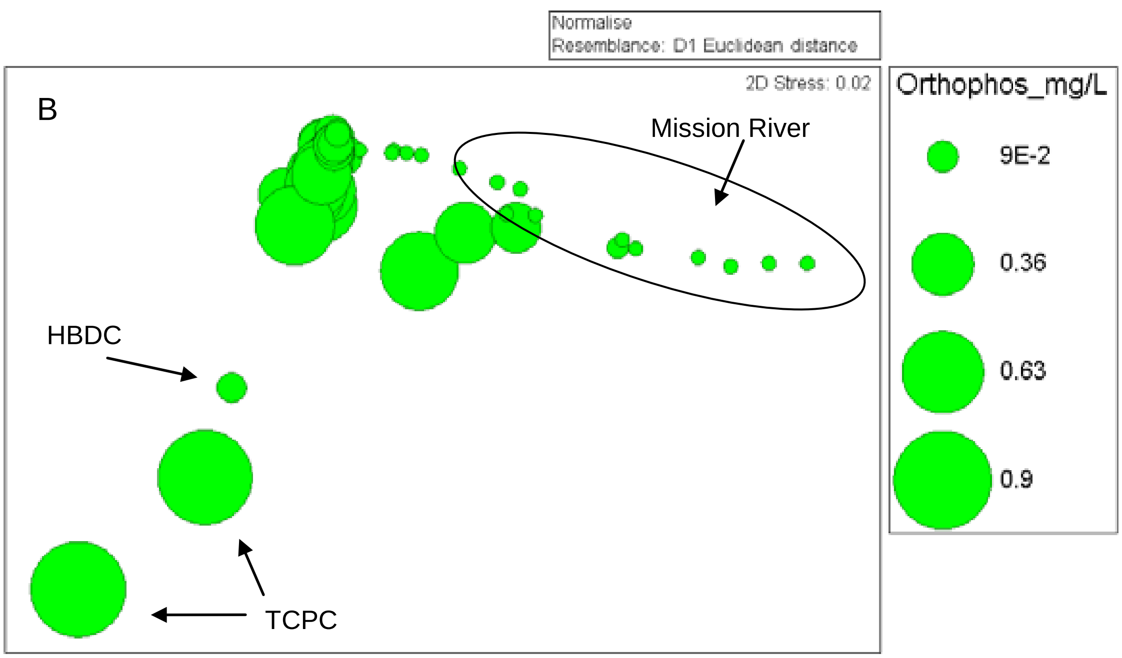


Figure 9. MDS configuration of the stations based on Fig. 8a, overlaid with A, Ammonia concentrations; and B, Orthophosphate concentrations of bottom waters from all studies. Size of each circle is represented by the scale at the right.

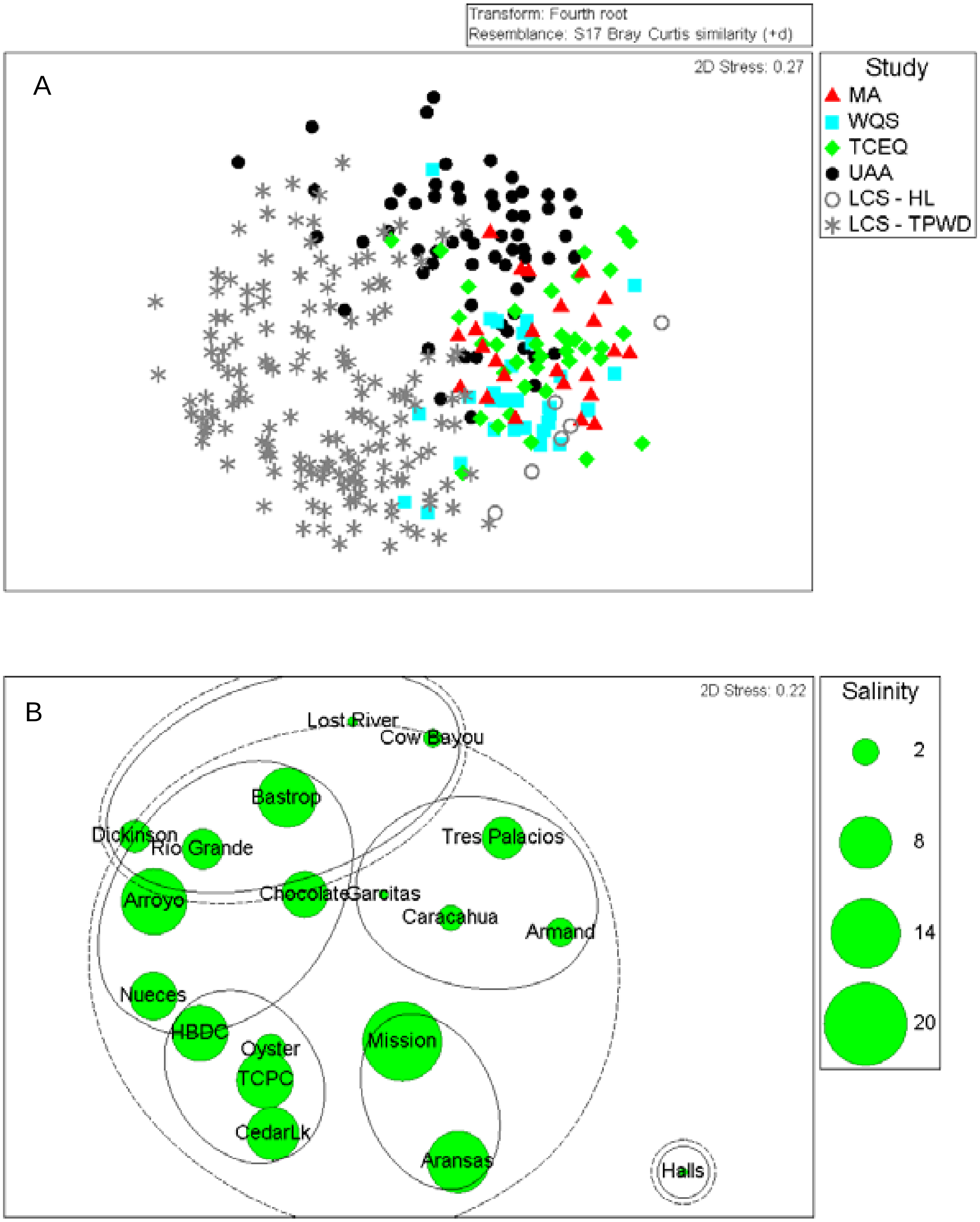


Figure 10. MDS configuration of the stations based on summer season nekton communities collected with seines; A - color coded by study; and, B – MDS means plot by river, overlaid with mean salinities (size of each circle is represented by the scale at the right). Significance determinations follow the α value and Euclidean distance measure outlined in Fig. 6.

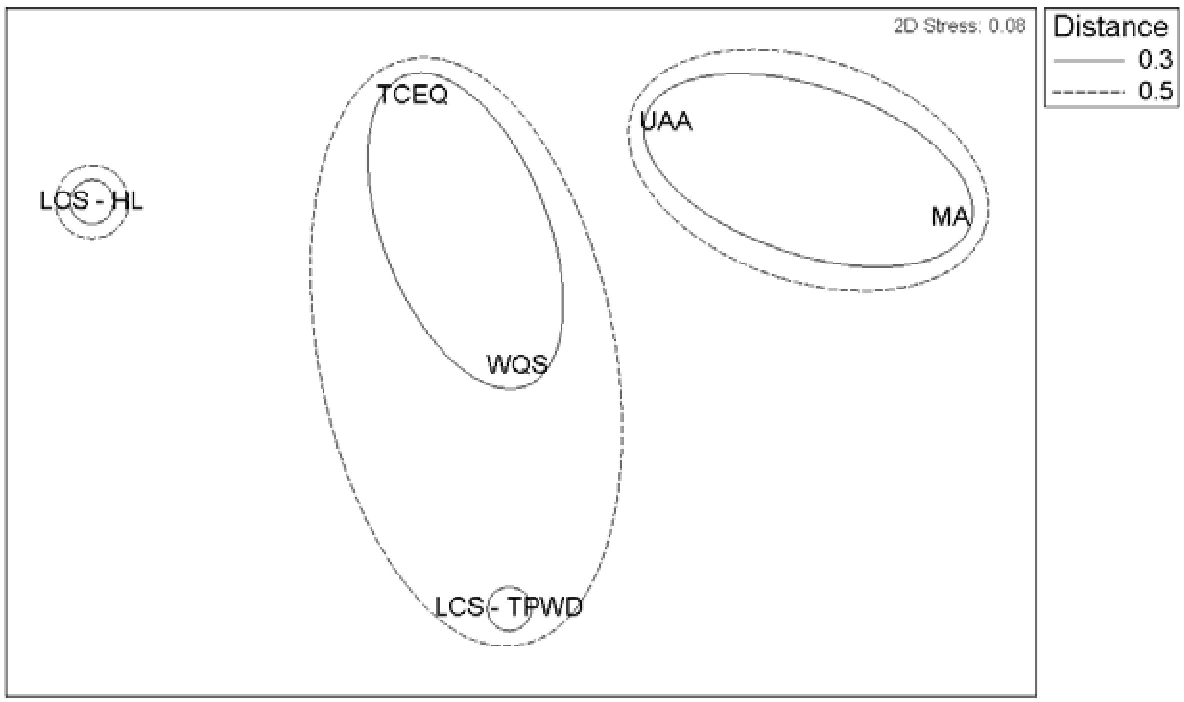


Figure 11. Means plot MDS ordination of the different studies, based on summer season nekton communities collected with seines. Significance determinations follow the α value and Euclidean distance measure outlined in Fig. 6.

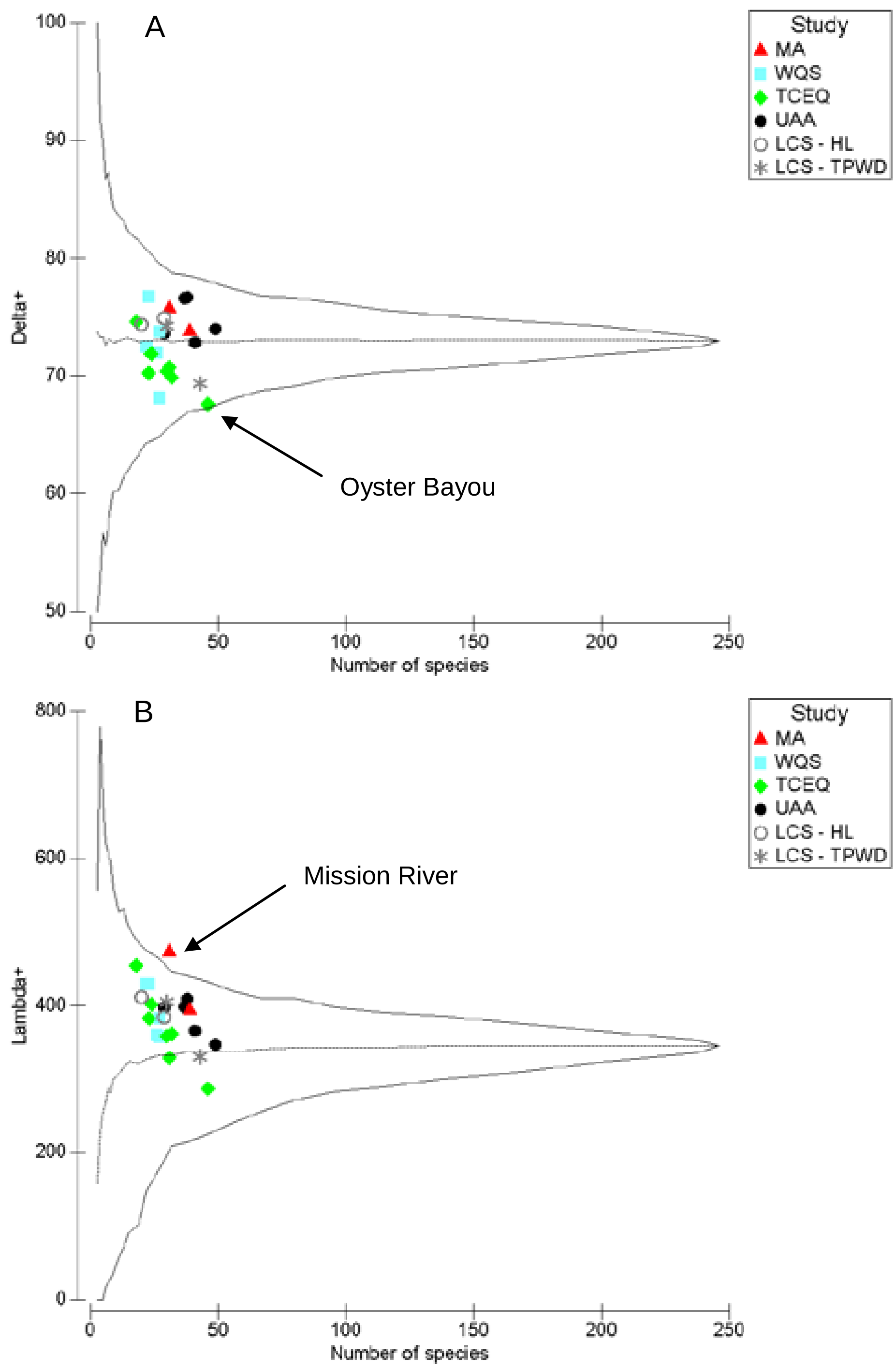


Figure 12. Funnel plot for simulated Average Taxonomic Distinctness (A) and Variation in Taxonomic Distinctness (B) of seine collections, from 999 sublists drawn randomly from a master species list of 179 taxa. Upper and lower control lines represent the 95% probability limits of the simulated values; thin line indicates theoretical mean. Points are color-coded by study and represent the mean Diversity values of seine collections at each location.

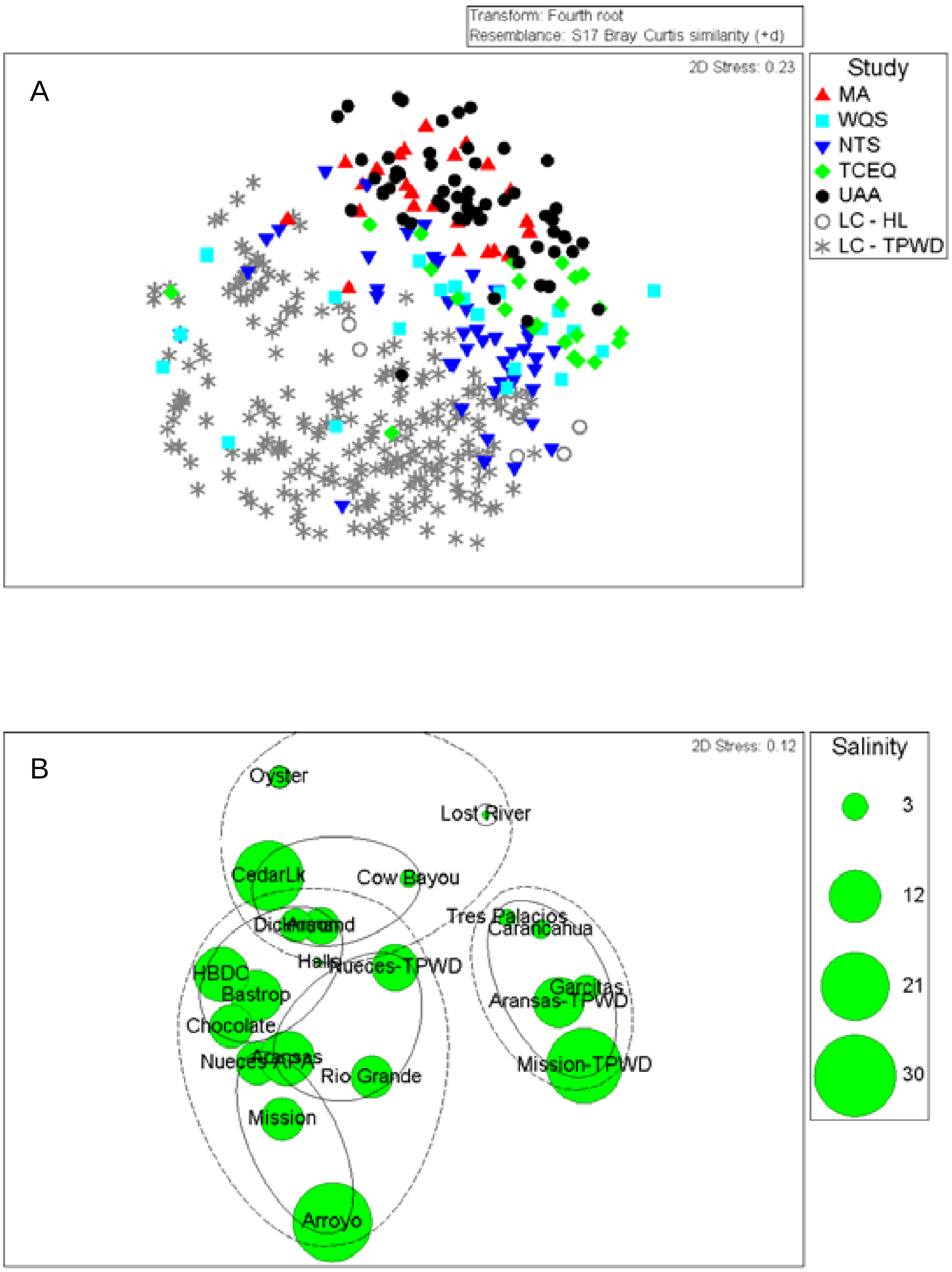


Figure 13. MDS configuration of the stations based on summer season nekton communities collected with otter trawls; A - color coded by study; and, B – MDS means plot by river, overlaid with mean salinities (size of each circle is represented by the scale at the right). Significance determinations follow the α value and Euclidean distance measure outlined in Fig. 6.

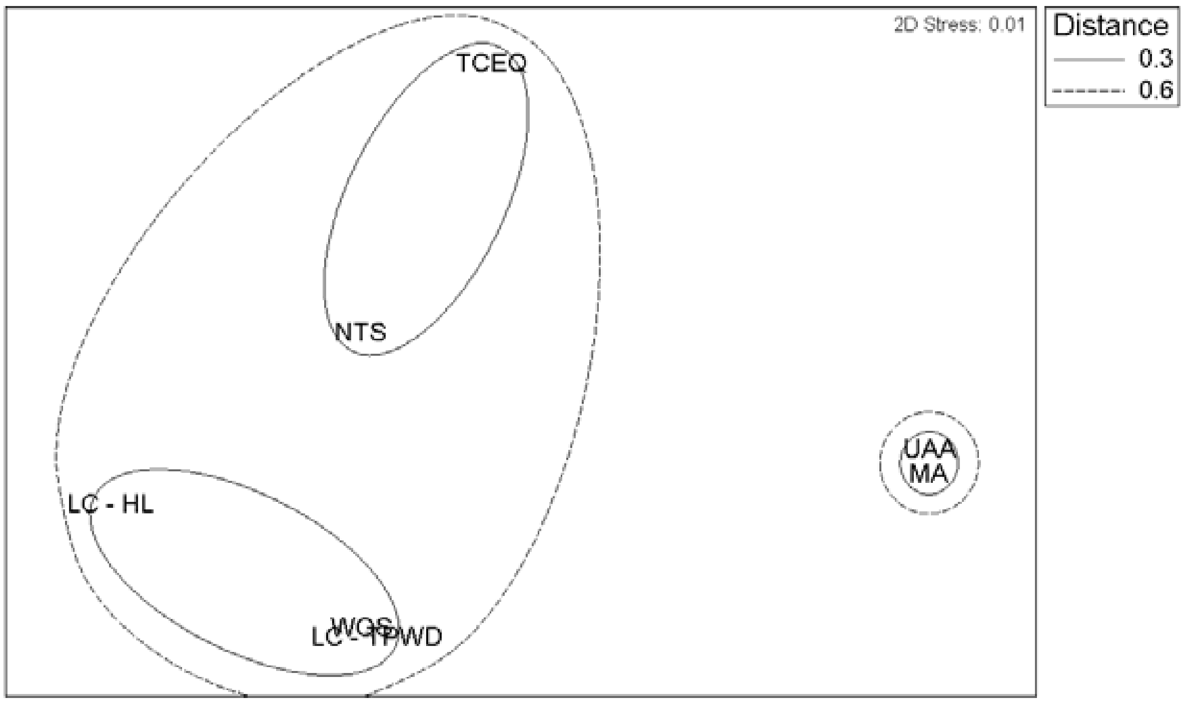


Figure 14. Means plot MDS ordination of the different studies, based on summer season nekton communities collected with otter trawls. Significance determinations follow the α value and Euclidean distance measure outlined in Fig. 6.

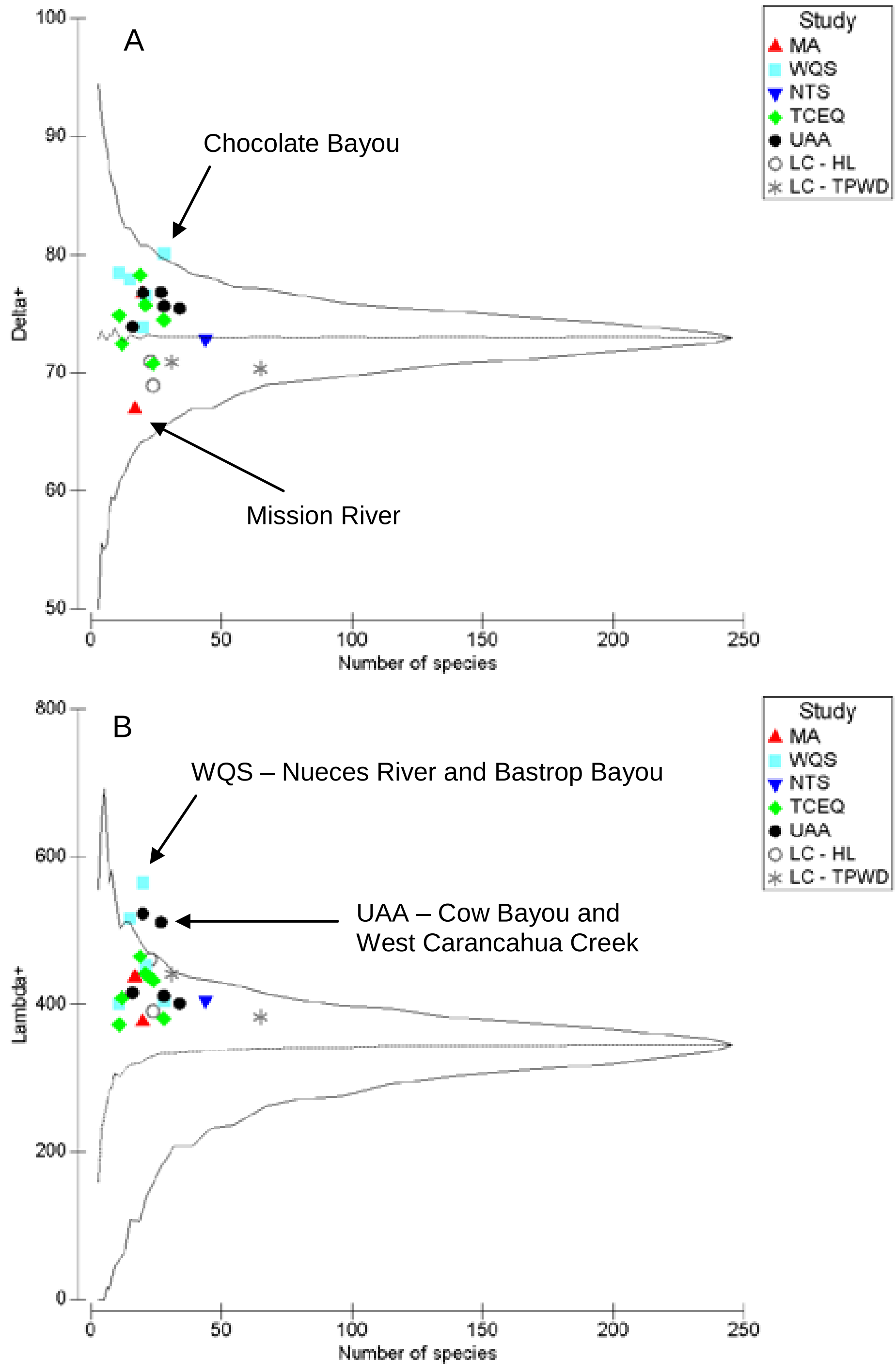


Figure 15. Funnel plot for simulated Average Taxonomic Distinctness (A) and Variation in Taxonomic Distinctness (B) of otter trawl collections, from 999 sublists drawn randomly from a master species list of 176 taxa. Upper and lower control lines represent the 95% probability limits of the simulated values; thin line indicates theoretical mean. Points are color-coded by study and represent the mean Diversity values of trawl collections at each location.

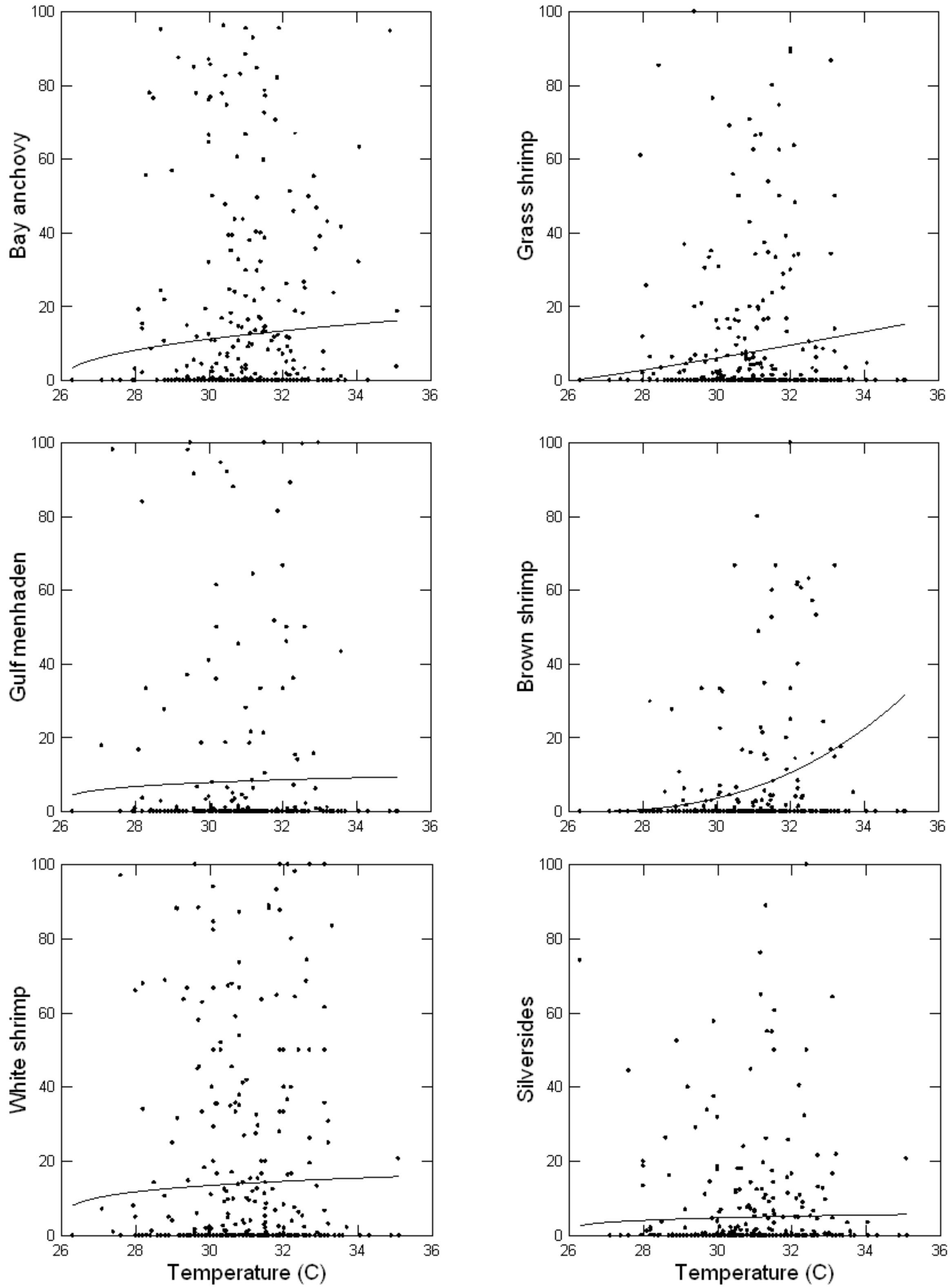


Figure 16. Scatterplots of the relationship between the relative abundance (% of Total, by collection) of the most common nekton, as recorded by shallow-water seines, and surface-water temperature during the summer season across all studies. Trend line is a non-linear power function in the form $E[y] = a * x^b$.

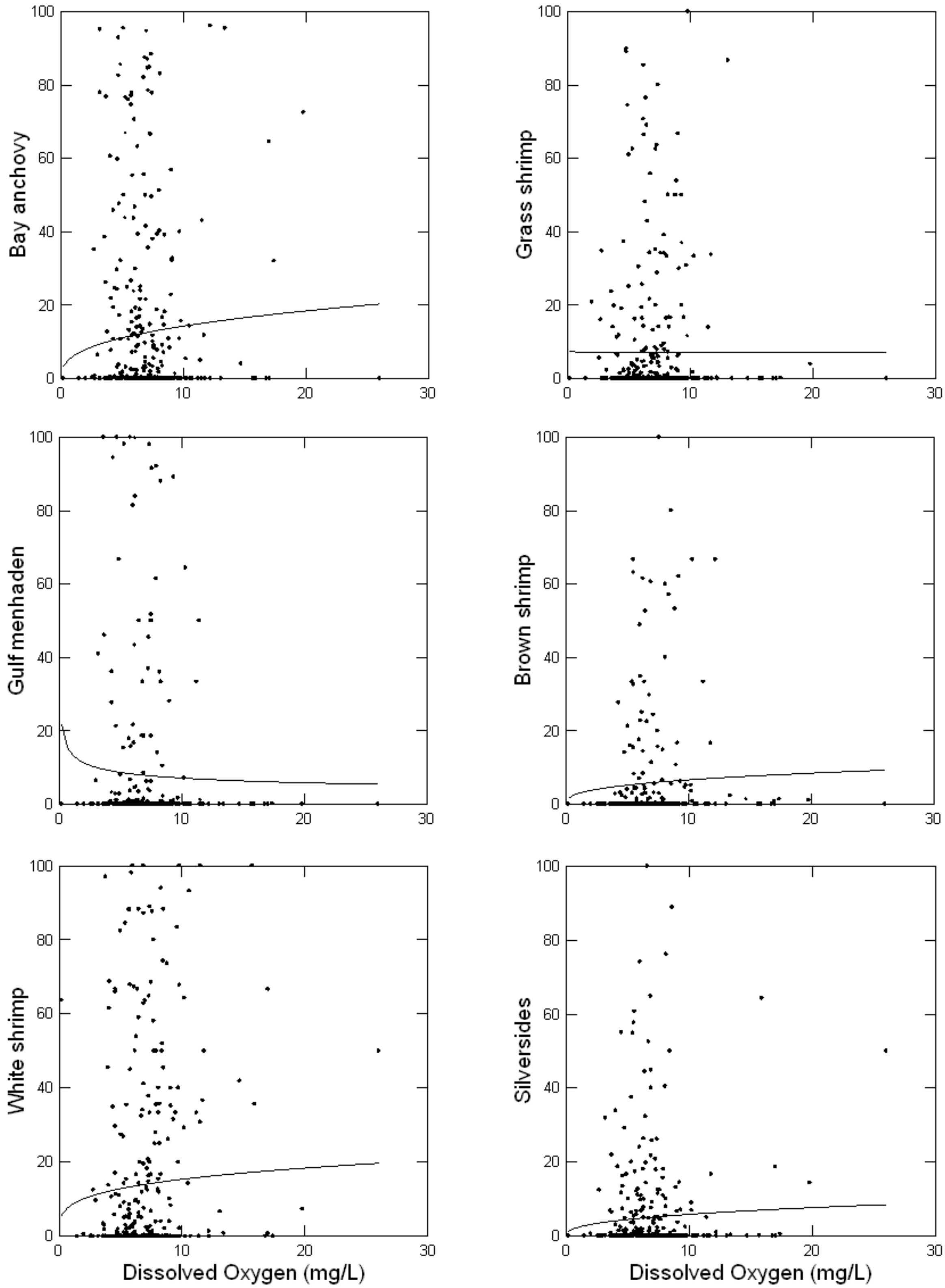


Figure 17. Scatterplots of the relationship between the relative abundance (% of Total, by collection) of the most common nekton, as recorded by shallow-water seines, and surface-water DO concentrations during the summer season across all studies. Trend line is the non-linear power function outlined in Fig. 16.

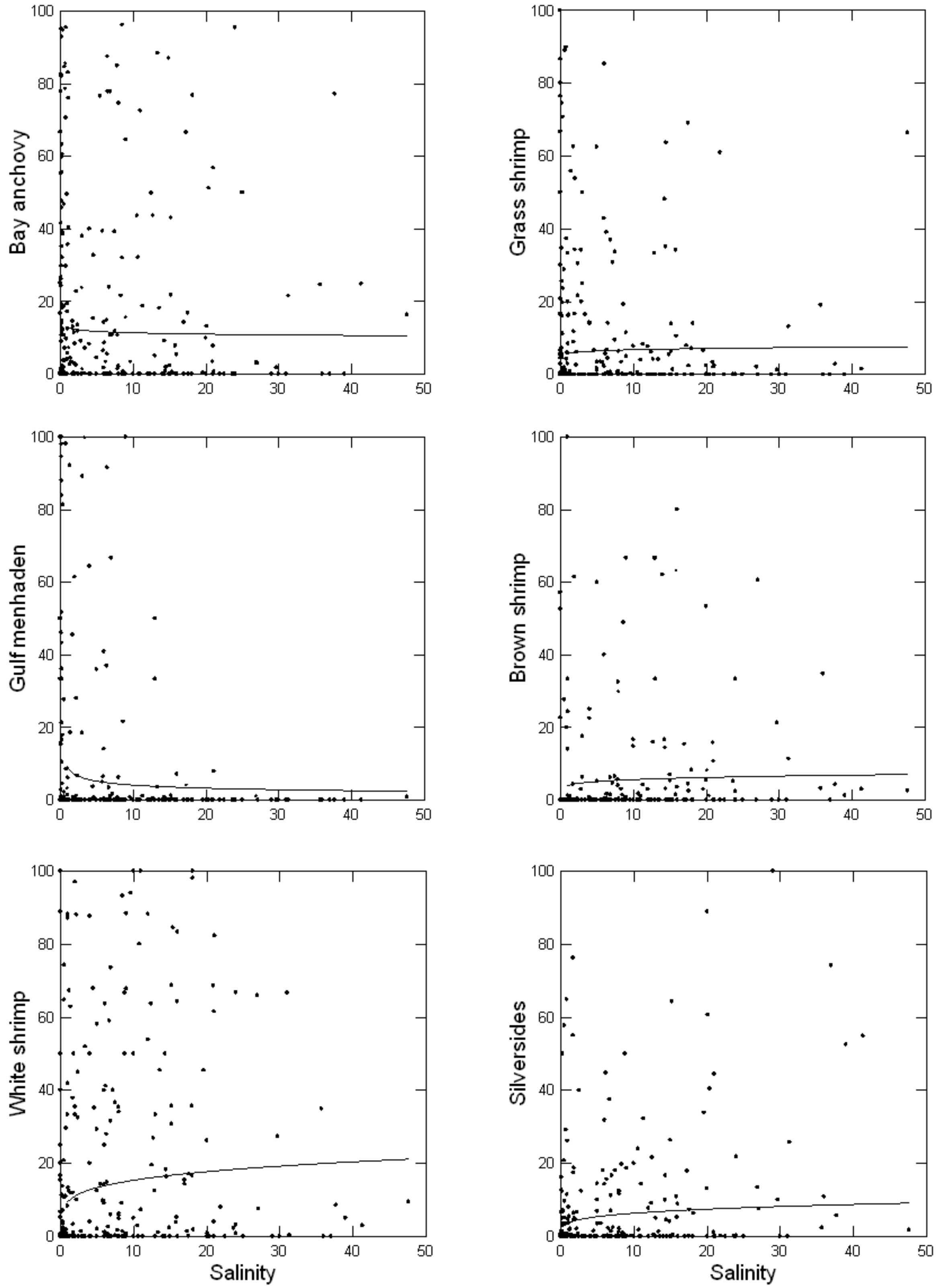


Figure 18. Scatterplots of the relationship between the relative abundance (% of Total, by collection) of the most common nekton, as recorded by shallow-water seines, and surface-water salinity during the summer season across all studies. Trend line is the non-linear power function outlined in Fig. 16.

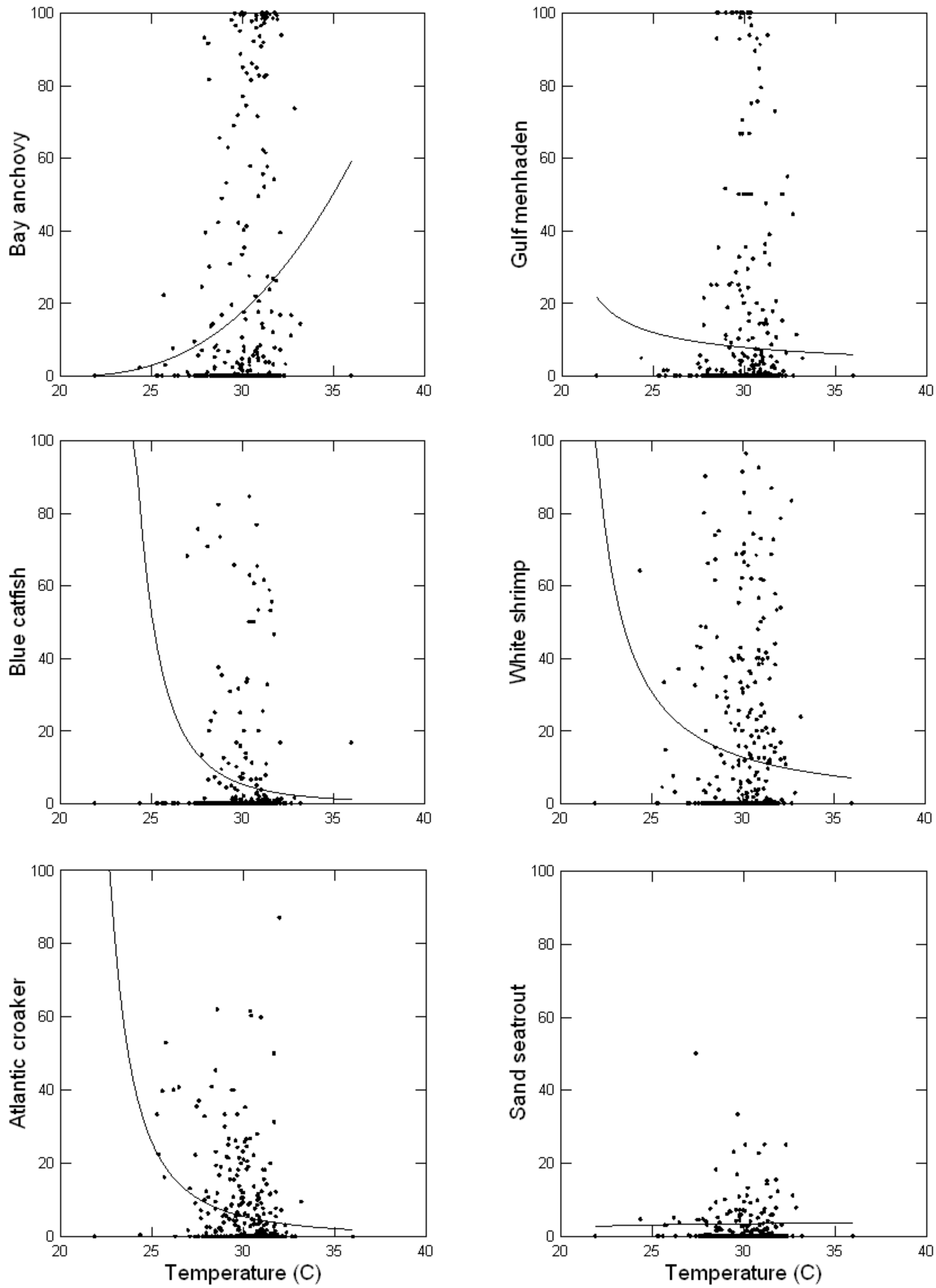


Figure 19. Scatterplots of the relationship between the relative abundance (% of Total, by collection) of the most common nekton, as recorded by otter trawls, and bottom-water temperature during the summer season across all studies. Trend line is the non-linear power function outlined in Fig. 16.

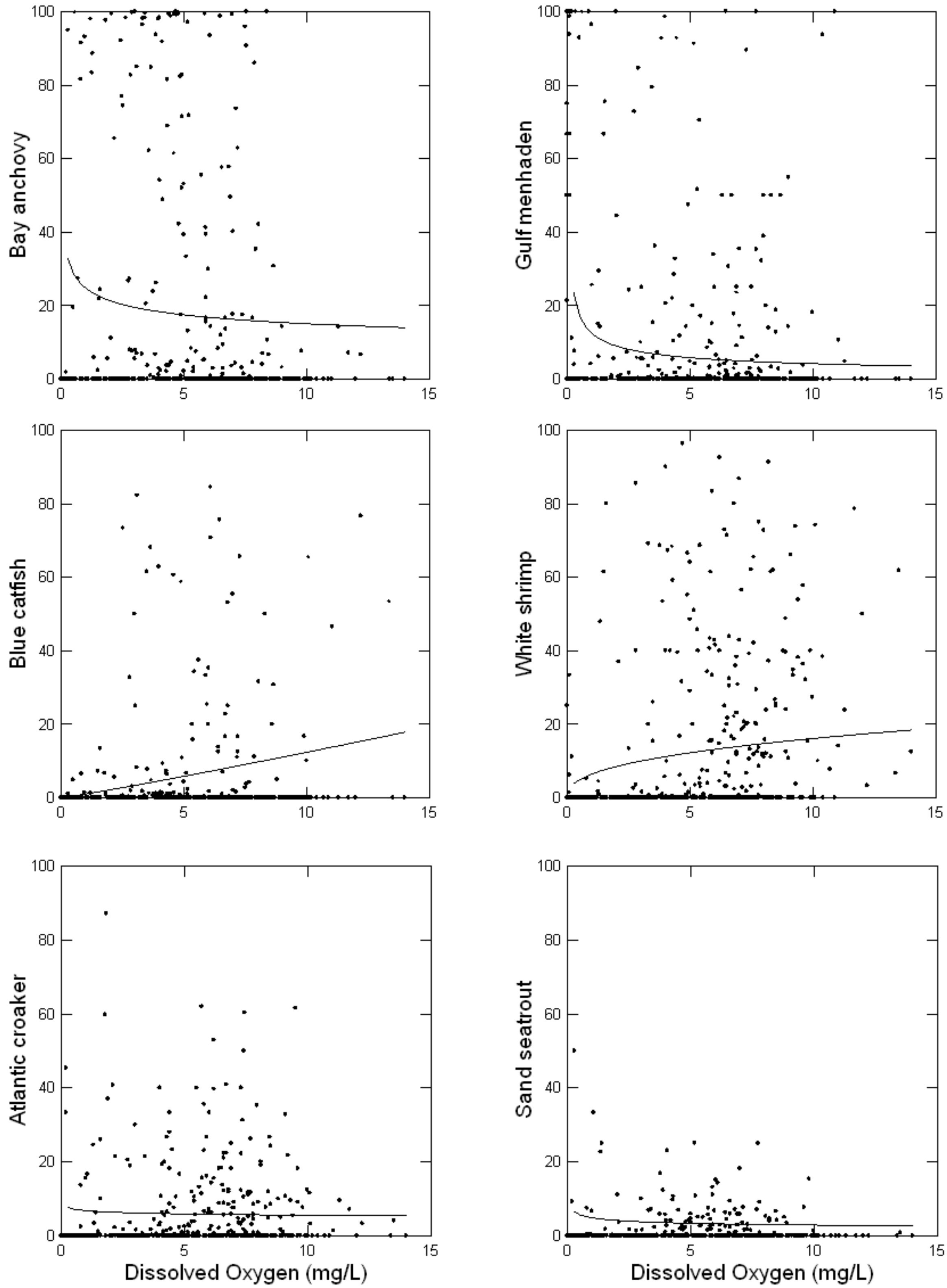


Figure 20. Scatterplots of the relationship between the relative abundance (% of Total, by collection) of the most common nekton, as recorded by otter trawls, and bottom-water DO concentrations during the summer season across all studies. Trend line is the non-linear power function outlined in Fig. 16.

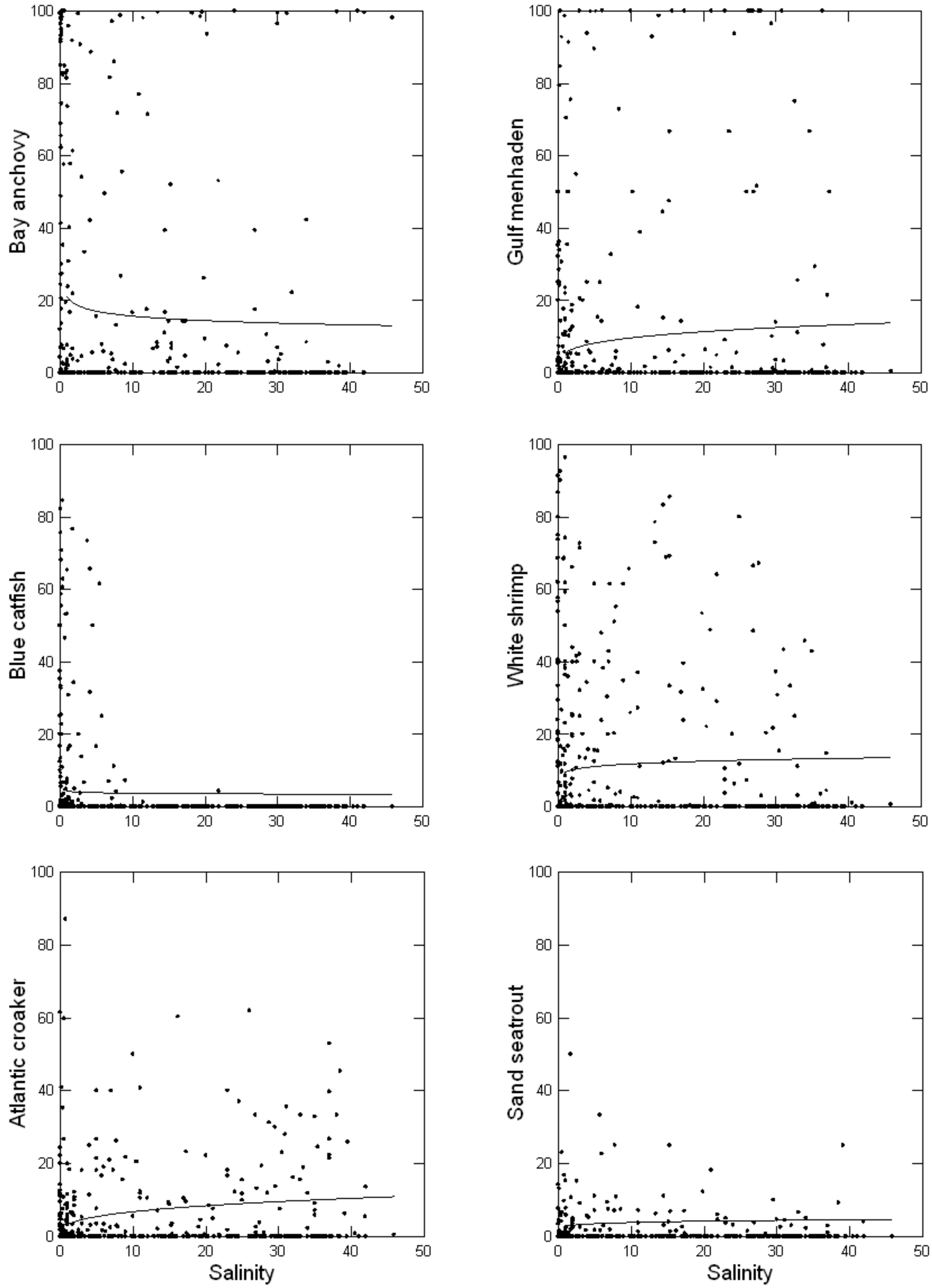


Figure 21. Scatterplots of the relationship between the relative abundance (% of Total, by collection) of the most common nekton, as recorded by otter trawls, and bottom-water salinity during the summer season across all studies. Trend line is the non-linear power function outlined in Fig. 16.