Historical Fisheries Data Analyses for Restoring the Rookery Bay Estuary Project

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Rookery Bay
National Estuarine Research Reserve

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Restoring the Rookery Bay Estuary Project

Final Report to
Rookery Bay National Estuarine Research Reserve
as part of the *Restoring the Rookery Bay Estuary* Project

Submitted to:
Tabitha Stadler, Project Lead
Rookery Bay National Estuarine Research Reserve
300 Tower Road, Naples FL 34113

Submitted by:
Jeffrey R. Schmid
Environmental Science Division, Conservancy of Southwest Florida,
1495 Smith Preserve Way, Naples, FL 34102
E-mail: jeffs@conservancy.org
TEL: 239-403-4225
FAX: 239-262-5872

and

Patrick O'Donnell
Research Department, Rookery Bay National Estuarine Research Reserve
300 Tower Road, Naples FL 34113
E-mail: Patrick.ODonnell@dep.state.fl.us
TEL: 239-530-5966
FAX: 239-530-5983

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INTRODUCTION

During the 1950s and 60s, dredge and fill operations in southwest Florida transformed vast tracts of mangrove forest into large-scale waterfront home sites (Antonini et al., 2002). In Collier County, concerns that expanding development between Naples and Marco Island would eliminate the mangrove forest between the two communities prompted a grass-roots advocacy group to protect the Rookery Bay estuary. The Collier County Conservancy, later named the Conservancy of Southwest Florida, formed in 1966 and, with assistance of the Nature Conservancy and National Audubon Society, purchased privately-owned land around Rookery Bay and Henderson Creek. The 4,000 acres (1,618 hectares) of bays, islands, and mangrove shoreline were designated the Rookery Bay Sanctuary, an Audubon Wildlife Sanctuary (Anonymous, 1968; Yokel, 1983). The aforementioned founding organizations transferred land management responsibilities to Florida Department of Natural Resources, now Florida Department of Environmental Protection, in a 1977 lease agreement and requested the State to apply to National Oceanic Atmospheric Administration for National Estuarine Research Reserve (NERR) status (FDEP, 2013). Rookery Bay NERR was formally designated in 1978 as the third such reserve in the nation and the estuarine complex subsequently protected for long-term research, water-quality monitoring, education and coastal stewardship.

Freshwater inflow to Rookery Bay is provided by a number of small tidal creeks and canal systems, making this estuarine system sensitive to changes in upland drainage. As with other South Florida estuaries (Macauley et al., 2002), the Rookery Bay watershed has been subjected to rapid expansion of agricultural and urban development, widespread drainage and flood control via canals, altered freshwater inflow and hydroperiods, and loss of wetland acreage. Alterations to the watershed began as early as the 1920s with the construction of Tamiami Trail/U.S. Highway 41 and the canal paralleling the roadway. There were major modifications to the freshwater inflow in the late 1950s with construction of State Road/County Road 951 (Collier Boulevard) and the resulting borrow canal that connected to Henderson Creek, a primary tributary to the estuary. Additional canal systems were created for Naples Manor in the 1960s and the Lely Development in the early 1970s (Delate and Haner, 1994). In the 1980s, water control structures (i.e., weirs) were placed in the Henderson Creek Canal to retain freshwater during the winter dry season and release water during the summer rainy season. This water management scenario has resulted in higher mean salinities in the Rookery Bay estuary for most of the year but also periods of extreme salinity fluctuations during the rainy season (Shirley et al., 2004, 2005).

Fish communities are often used as indicators of hydrologic alterations in estuarine waters and there have been a number of trawl studies in the backwater bays of Collier County in these regards (Carter et al., 1973; Colby et al., 1985; Browder et al., 1986; Shirley et al., 2005). These studies focused on geographical differences in estuarine conditions and fish aggregations, comparing the highly altered Faka Union Bay in the Ten Thousand Islands archipelago to bay systems to the east and west. Colby et al. (1985) qualitatively compared the occurrence of dominant fish species to that of Carter et al. (1973) 10 years earlier but there have been no quantitative analysis of temporal patterns in fish compositions relative to changes in freshwater inflow. A series of trawl surveys were conducted in Rookery Bay between 1970s and 2010s which offer an opportunity to investigate long-term patterns of fish community composition in this estuarine system. The purpose of our study was to analyze this historic fisheries data as part of the *Restoring the Rookery Bay Estuary* project. The objectives were to analyze the temporal trends of fish composition in the Rookery Bay estuary over a 40 year period and to identify indicator fish taxa with regards to the possible effects of altered freshwater inflows and salinity in the system.

MATERIALS AND METHODS

Study Area

Rookery Bay is a shallow lagoonal estuary located in western Collier County, Florida (Fig. 1). The estuarine complex is comprised of smaller embayments partially separated by mangrove islands and includes bathymetric features such as oyster reefs and sand/mud flats. The western boundary is delineated by a series of barrier islands with inlets connecting to the Gulf of Mexico to the north (Gordon Pass) and south (Hurricane Pass and Big Marco Pass). Approximately two-thirds of the tidal exchange occurs through the southern region of the bay system given a deeper channel and proximity to Gulf inlets (Anonymous, 1968). The eastern boundary is undeveloped red mangrove (*Rhizophora mangle*) shoreline with tidal creeks that contribute freshwater to the estuarine system. Sand Hill and Stopper Creeks flow into the northern region of Rookery Bay and Henderson Creek flows into the southern region.

Rainfall patterns in southern Florida, and the subsequent salinity conditions in the estuaries, vary seasonally and were categorized by Shirley et al. (2004) as early dry season (December through February), late dry season (March through May), early wet season (June through August), and late wet season (September through November). Wet season rainfall is produced primarily by localized thunderstorms, although tropical cyclones can increase rainfall substantially when they cross or come close to south Florida (Duever et al., 1994). Urban areas to the north and east of Rookery Bay rely on drainage canals for flood control during the wet season and the storm water is conveyed to the bay via the aforementioned tributaries. These canal systems also have water level control structures, such as the weir at the head of Henderson Creek, which serve to retain water during the dry season. As such, seasonal salinity patterns in the Rookery Bay estuary can be more influenced by stormwater management than by rainfall and tidal exchange (Shirley et al., 2005).

Data Collection

Three fisheries studies have been performed within the Rookery Bay estuarine complex using similar sampling gear (otter trawls) and protocol (night sampling at 4 stations):

(1) Yokel (1983) University of Miami dissertation from June 1970 to July 1972

(2) Rookery Bay "Learning Through Research" (unpubl. data) from January 1990 to December 1991

(3) Wilke (in prep.) Florida Gulf Coast University thesis from July 2011 to June 2013

There were a number of differences among the datasets that had to be addressed when creating a combined database:

(1) The 1990s dataset had a time scale based on the calendar year whereas the 1970s and 2010s datasets correspond to seasonal changes in rainfall

patterns (wet season – June to November, dry season – December to May). Nonetheless, there are 24 sampling events over a 2-year period for the 1990s data and these can be assigned a seasonal factor as with the other data.

(2) The 1970s dataset was based on a lunar cycle rather than a monthly schedule and, as a result, had an extra sampling event in August 1970. This discrepancy was rectified by averaging the fish abundance for the month with 2 sampling events.

(3) The 1970s dataset also overlaps with regards to the start and finish dates giving 2 extra sampling events. The first sampling event (June 1970) and the last sampling event (July 1972) were omitted to give a total of 24 sampling events corresponding to the July-June timeframe of the 2010s dataset.

(4) All studies performed 7 hauls/replicates at each station for a given sampling event but the data available for the 1970s dataset was summed at each station per sampling event. The 1990s and 2010s datasets were summed accordingly giving a monthly total at each station as the lowest level of replication.

(5) There were some possible issues with fish species identification in the 1970s and 1990s studies that were rectified by creating taxonomic complexes (combining questionable and/or rare taxa in groups of species, genera, or families). For example, the 1970s study combined the species of herrings and sardines into a single family Clupeidae whereas the 1990s and 2010s studies separated by species, so the latter studies were combined to family level to be comparable with the first study. There were also a couple instances of the

earlier studies having a single fish of questionable identification that were combined with related taxa to create genera and species complexes.

Yokel (1983) selected 4 sampling stations within the Rookery Bay estuary after a survey to determine the major habitat types that could be effectively sampled with a small otter trawl (Fig. 1). These stations were used in the subsequent studies but there may have been differences in how the trawl was deployed at a given site (i.e., north-south transects vs. east-west transects).

(1) Station 1 (T1) was located in the northwestern region of Rookery Bay proper. Yokel qualitatively described this area as having “the densest vegetation cover”, primarily Cuban shoalweed (*Halodule wrightii*) with lesser amounts of turtlegrass (*Thalassia testudinum*) and stargrass (*Halophila englemanii*) in deeper waters, as well as seasonal accumulations of drift algae (*Laurencia* sp. and *Gracilaria* sp.). The substrate was a mix of sand, mud, and shell fragments.

(2) Station 2(T2) was located in the central region of Rookery Bay. Yokel designated the substrate was predominately mud with no vegetative cover other than “a few occasions” of drift algae.

(3) Station 3 (T3) was located in the southeastern region of the estuarine complex in an embayment known as Hall Bay. This sampling station was positioned along the red mangrove shoreline and Yokel indicated it had seagrass cover and composition similar to Station 1but “less dense” as well as seasonal accumulations of drift algae. The substrate was a mix of sand, mud, and shell fragments.

(4) Station 4(T4) was located in the lower region of Henderson Creek in the channel connecting to Hall Bay. Yokel described this area as having “few seagrasses or attached vegetation” and the vegetation usually collected was drift algae. This station experienced more tidal current than the others and therefore had a coarser substrate of sand and shell fragments.

Benthic habitat mapping (side-scan sonar and bottom grab sampling; Locker and Wright, 2003) was performed in the study area during 2002 and seagrasses were only collected in the northwestern portion of Rookery Bay. Ninety grab sample sites were located throughout the bay and identifiable seagrasses were only collected at 2 sites, one to the east (paddlegrass; *Halophila decipiens*) and the other to the west (Cuban shoalweed) of trawl Station 1. Other areas identified as submerged aquatic vegetation by side-scan sonar may have been macroalgae rather than seagrass. In-water visual surveys prior to the 2010s sampling did not detect the presence of seagrasses at Station 1 and, although visibility was poor, dark areas suspected to be submerged vegetation at Station 3 were in fact clusters of the oyster *Crassostrea virginica* (O’Donnell and Schmid, *pers. obs.*). Nonetheless, minute quantities of stargrass and paddlegrass, as well as greater quantities of drift algae, were collected at all stations during the 2010s trawl sampling.

<u>Data Analysis</u>

PRIMER v6 statistical software (PRIMER-E Ltd., Plymouth, UK; Clarke and Gorley, 2006) was used to analyze the fish compositions among the 3 datasets. Fish abundance was square root transformed to down-weight the more abundant species. Bray-Curtis similarity matrices were created for transformed fish abundances. Analysis of similarity (ANOSIM), similar to the parametric analysis of variance (ANOVA), was used to test the null hypothesis that there are no differences among fish communities versus the alternative hypothesis that two or more of the communities differ with regards to factors within each dataset (year counts, sampling stations, and seasons) and between datasets (studies and seasons). In the event of a significant difference in the ANOSIM global test, multiple comparisons are performed for 3 or more groups to determine which differ from one another. A matrix of pairwise R values is generated whereby large values ($R \approx 1$) indicate high differentiation between groups, while small values ($R \approx 0$) imply little or no difference. R values are not unduly affected by the number of replicates/permutations, unlike the significance levels (p-values), and are therefore the best measure of differences between groups (Clarke and Gorley, 2006; Clarke and Warwick, 2001).

For each dataset, one-way ANOSIM was used to test for differences between year counts (Year1 vs. Year 2) and two-way crossed ANOSIM was used to test for differences among sampling stations and between seasons (wet vs. dry). In this case, the two-way crossed ANOSIM tests the null hypothesis of no difference in fish communities among sampling stations, allowing for the fact there may be differences between seasons, and also the null hypothesis of no difference between seasons allowing for the possibility of differences among stations. The similarity percentages routine (SIMPER) was used to determine the fish taxa that may have contributed to any seasonal dissimilarity within each dataset.

The SIMPER routine is useful in identifying the contributions by individual taxa to the similarity or dissimilarity between pairs of well-defined groups; however, identifying a subset of taxa that ‘best explain’ the continuous pattern for all taxa would be more parsimonious in identifying indicator species (Clarke and Gorley, 2006). The BVSTEP option under the BEST routine was used identify a subset of taxa, or indicators, that characterized the fish community composition patterns for each dataset. An initial subset of approximately 10% of the full taxonomic list and 100 random restarts were used to determine the smallest subset of taxa with the highest Spearman correlation coefficient (ρ) and number of restarts.

The 3 datasets were combined and square root transformation was applied to the fish abundances in the combined dataset. Monthly transformed abundances were then averaged by study, sampling site, and season. A Bray-Curtis similarity matrix was created and hierarchical clustering with group-average linking and multi-dimensional scaling (MDS) were applied to evaluate the group structure among the studies, sampling sites, and seasons. The similarity profile permutation test (SIMPROF) was used to identify coherent clusters, or groups, in the dendogram using a significance level of $p < 0.05$ (5%). SIMPROF tests the null hypothesis that a specified set of studies, stations, and seasons do not differ from each other in multivariate structure. Two-way crossed ANOSIM was used to test for differences among studies and between seasons for the combined dataset and two-way SIMPER was used to identify fish taxa contributing to any dissimilarity.

The ANOSIM routine indicates an undefined difference between groups but there is the *a priori* expectation that the fish composition in Rookery Bay has changed during the 40 year period owing to altered hydrology and/or other anthropogenic disturbances; therefore, a test for temporal seriation (Clarke and Gorley, 2006; Somerfield et al.,

2002) was performed on the combined dataset for each sampling station and season. A model matrix of seriation with replicates was constructed from the Bray-Curtis matrix of each group and the RELATE routine was used to test the null hypothesis of no ordered sequence of fish composition change among studies.

RESULTS

Data Overview

A total of 72 taxonomic units of fish were identified during the Rookery Bay trawl surveys (Table 1) including 2 classes, 40 orders, 40 families, and at least 58 genera and 62 species of fishes. There were also 2 family, 3 genera, and 5 species complexes used in the analyses. *Eucinostomus* spp. (referred to as “Eucinostomus mojarras” hereafter) were the most abundant taxa for all studies combined (Table 2) and dominated the catch for the 1990s (65% of dataset total) and 2010s (58% of dataset total). *Lagodon rhomboides* (pinfish) was the most abundant taxon during 1970s (46% of dataset total) followed by Eucinostomus mojarras (30% of dataset total). By comparison, pinfish accounted for 5% of the catch in the 1990s and 11% in 2010s.

Individual Dataset Analyses

Each of the Rookery Bay fisheries studies were of 2-year duration and the very low *R* values (0.024 - 0.043; Table 3) from one-way ANOSIM comparisons indicate the fish communities did not differ between the years of each study. For the 1970s dataset, Yokel (1983) noted fish kills in Rookery Bay as well as the lowest fish abundance and species richness following a bloom of red tide algae *Karenia brevis* in May and June 1971. However, the possible effects of this red tide event were masked by the seasonal recruitment of more abundant species, such as Eucinostomus mojarras, following the event and therefore did not result in a difference in the fish communities between year counts. This was probably the case for the 1990s and 2010s datasets as the seasonal recruitment of more abundant species obscured any annual differences of less abundant species despite the data transformation.

Two-way crossed ANOSIM comparisons for the sampling stations and seasons of each dataset indicated highly significant differences in stations but each dataset had Global R values less than 0.25 (Table 3) indicating little to no differences in the respective fish communities. Nonetheless, the differences among stations were greatest in the 1970s dataset (Global R = 0.229) and then decreased in the 1990s (Global R = 0.145) and 2010s (Global R = 0.103). Pairwise comparisons for the 1970s dataset (Table 4) demonstrate that stations with seagrass habitat (Station 1 and Station 3) have slightly different fish communities than those with little or no attached vegetation (Station 2 and Station 4) and these differences were no longer evident in the 1990s or 2010s datasets.

Two-way crossed ANOSIM comparisons for the sampling stations and seasons of each dataset also indicated highly significant differences between wet and dry seasons and the intermediate R values support seasonal dissimilarities in the fish communities of each dataset (Table 3). Seasonal differences were lowest in the 1970s (Global R = 0.341) with increasing differentiation in 1990s (Global R = 0.423) and again in 2010s (Global R = 0.573).

SIMPER analyses demonstrated that 5 of the 72 fish taxa collected in Rookery Bay contributed the most to the seasonal differences in each dataset (Table 5).

Eucinostomus mojarras and *Lutjanus synagris* (lane snapper) were most abundant during the wet seasons and pinfish, *Orthopristis chrysoptera* (pigfish), and *Anchoa* spp. (anchovies) were most abundant during the dry seasons with different contributions by each taxa to the seasonal dissimilarities of the respective dataset. A temporal pattern is also suggested among the datasets with pinfish and Eucinostomus mojarras contributing most to the seasonal difference in the 1970s (16% each) and a greater contribution by Eucinostomus mojarras to the differences in 1990s (22%) and 2010s (26%).

The BVSTEP routine identified a set of 9 taxa for the 1970s, 9 taxa for the 1990s, and 4 taxa for the 2010s that represented the multivariate patterns of the entire fish community in the respective datasets (Table 6). The 2010s list was comprised of anchovies, Eucinostomus mojarras, pinfish and pigfish. These fish taxa also occurred in the 1970s and 1990s lists and this signifies their importance as indicator taxa in the Rookery Bay estuarine complex. Lane snapper and *Symphurus plagiusa* (blackcheek tonguefish) occurred in the 1970s and 1990s lists.

Combined Dataset Analyses

The trends in individual datasets were supported by the analyses of the combined dataset transformed and averaged by study (i.e., individual dataset), season, and station. Two-way ANOSIM comparisons for the studies and seasons indicated significantly distinct separation in fish communities between seasons (Global $R = 0.875$, $p = 0.0001$) with slightly less separation among studies (Global $R = 0.541$, $p = 0.0001$). Pairwise comparisons between studies indicated the greatest difference in fish communities was between 1970s vs. 2010s ($R = 0.661$, $p = 0.0008$) although the communities for 1970s vs. 1990s and 1990s vs. 2010s comparisons were also different (R = 0.552, p = 0.0008 for both).

As with individual datasets, SIMPER analyses of the combined dataset demonstrated that 5 of the 72 fish taxa collected in Rookery Bay contributed the most to the temporal and seasonal differences (Table 7). There was a substantial increase in abundance of Eucinostomus mojarras and a decrease in pinfish between the 1970s and 1990s, while anchovy abundance increased steadily from 1970s to 2010s. These taxa contributed the most to the temporal dissimilarities between studies. Seasonal patterns of abundance for the 5 fish taxa were the same in the individual and combined datasets with Eucinostomus mojarras and pinfish contributing the most to seasonal dissimilarities. Eucinostomus mojarras were most abundant during the wet season and pinfish during the dry season (Table 8). Anchovies were most abundant during the late dry season in 1970s and 1990s and the early dry season in 2010s, although their abundance was also relatively high during the late wet season for the latter dataset.

For the cluster and MDS analyses, there were 2 primary groupings of studies and stations by season at the 50% similarity level (Figs. 2 and 3). SIMPROF indicated the fish communities for the dry season group were significantly different (π = 3.16, p = 0.001) from those of the wet season group. The groupings by study and station during the dry season were not well-defined with a significantly different singlet (1970s Station 1; π = 2.39, p = 0.001) at 53% similarity, a significantly different couplet (1970s Stations 2 and 4; π = 1.91, p = 0.002) at 60% similarity, and the remainder of studies and stations were not significantly different (π = 1.28, p = 0.084) at 61% similarity. The wet season groups were significantly different by study and stations and these differences corresponded to alterations to habitat and hydrology over time. For the 1970s, there was a significantly different couplet (π = 4.41, p = 0.001) at 52% similarity corresponding to stations without seagrass (Stations 2 and 4) and a significantly different couplet (π = 3.83, p = 0.001) at 59% similarity corresponding to stations with seagrass. The 1990s station group was significantly different (π = 2.16, p = 0.001) from 2010s station group at 73% similarity. For the 1990s group, the couplet of Stations 2 and 3 was significantly different (π = 2.51, p = 0.002) from that of Stations 1 and 4 at 75% similarity, the latter of which correspond to stations closest to the tributaries and the freshwater inflow that has since been altered. For the 2010s group, Station 2 was significantly different (π = 1.95, p = 0.003) from the others at 77% similarity. This station is centrally located in Rookery Bay proper and perhaps the least influenced by the managed freshwater inflow.

Temporal Seriation

There was significant tendency for seriation of fish communities between studies at each of the sampling stations (Station 1 – ρ = 0.231, p = 0.0001; Station 2 – ρ = 0.295, p = 0.0001; Station 3 – ρ = 0.185, p = 0.0001; Station 4 – ρ = 0.262, p = 0.0001) but the relatively small Spearman correlation coefficients do not suggest a strongly ordered gradient. There was also significant seriation between studies by season with a much higher correlation for the wet season (ρ = 0.343, p = 0.0001), indicating a greater tendency for seriation, than the dry season (ρ = 0.178, p = 0.0001).

CONCLUSIONS

There are no water quality or fisheries data available for Rookery Bay prior to channelization in the watershed so there is no reference for baseline conditions in the estuary (Shirley et al., 2005). Nonetheless, Yokel (1975, 1983) performed some of the earliest fisheries trawl surveys in the region during the 1970s and these efforts pre-date some of the later alterations to freshwater inflow (i.e., Henderson Creek weir construction). Shirley et al. (2005), however, contend that historical data sets should not be used for developing performance measures in restoration projects given annual variation observed in species composition during their 2-year fisheries study. The authors reported significant differences in fish species composition by year using the ANOSIM procedure but failed to provide the *R* values from the comparisons. Recall that *R* values are the preferred measure for interpreting differences with this statistical procedure given that significance values are influenced by sample replication. Our ANOSIM analyses indicated significant differences between the years of each dataset but the very low *R* values (Table 3) suggest little or no annual variation in the fish communities of each study. We therefore counter that historical data sets can be used for providing baseline conditions provided there is minimal variability between subsequent years. We also recognize that data need to be collected continuously over longer periods of time to account for annual and seasonal variability in environmental parameters such as precipitation.

The results of our analyses indicate there have been significant changes in the fish communities of Rookery Bay estuary since the 1970s and these changes may be attributable to water management practices and possible habitat loss from the resulting hydrologic conditions. Most changes in the Rookery Bay fish assemblages occurred between the 1970s and 1990s with more similar compositions between 1990s and 2010s. This change corresponds to the installation of weirs in the headwaters of Henderson Creek in the 1980s and the subsequent modifications to timing and quantity of freshwater inflow. The compositions of fish communities among the sampling stations have become more similar to one another over time and this perceived trend may have resulted from the observed loss of seagrass habitat in Rookery Bay between the 1970s and the 2010s. Lastly, fish assemblages during the wet season have become increasingly different over time from those in the dry season. This trend could also be the result of hydrologic alterations in the watershed during the 40 year interim, most notably the installation of the weirs in Henderson Creek Canal. Stevens et al. (2008) found that the influence of freshwater inflow on fish community structure was greatest during the wet season when salinity gradients become more fully established and this is the period when extreme salinity fluctuations occur in Rookery Bay due to the release of stormwater via the weirs.

Salinity has traditionally been the central parameter in estuarine analyses (Orlando et al., 1993) but there are many environmental factors that determine the distribution of fish in time and space. The results of our study indicate five fish taxa (pinfish, Eucinostomus mojarras, anchovies, pigfish, and lane snapper) contributed the most to the historical differences in the Rookery Bay fish community and trends in the abundance of these taxa can be correlated to their respective salinity tolerances or preferences relative to anthropogenic alterations of freshwater inflow to Rookery Bay. However, other factors such as bottom type and food resources need to be recognized as potential alternatives to the influence of inflow on fish abundance patterns (Stevens et al., 2008).

RESEARCH RECOMMENDATIONS

(1) Habitat mapping has been performed in the Rookery Bay estuary using side-scan sonar and efforts are currently underway using photointerpretation of aerial images. In both cases, however, identification of benthic habitats is inferred from remotely-sensed data with limited ground truthing. Furthermore, these methods do not allow for differentiation among species of seagrasses or macroalgae and often group these as a single habitat type (i.e., submerged aquatic vegetation). Species-specific distributions of benthic vegetation are commonly used as indicators of estuarine conditions in the nearshore waters of Florida and similar studies are needed to adequately manage and protect aquatic habitat in the Rookery Bay estuary. A comprehensive mapping technique has been developed using a systematic sampling scheme and benthic sampling gear to create a geographic information systems database of benthic habitat distributions. This method has been used to analyze the benthic habitat characteristics of the Naples Bay, Clam Bay, and Estero Bay relative to the respective estuarine conditions and is needed to complement existing efforts on Rookery Bay.

(2) Automated datasondes have been deployed to collect water quality data and discern estuarine conditions in the backwater bays of the Ten Thousand Islands as well as Rookery Bay. Regarding the latter, continuous water quality monitoring has been limited to a single site in Henderson Creek (corresponding to Station T4 in the

current study). Additional datasonde sites are needed, such as the northwestern region of Rookery Bay (corresponding to Station T1), to adequately characterize the patterns of freshwater inflow and salinity in this estuarine system.

(3) Populations of porcelain crab (*Petrolisthes armatus*; stenohaline) and flatback mud crab (*Eurypanopeus depressus*; euryhaline) inhabiting oyster habitat have been sampled using artificial substrates and the ratio of stenohaline to euryhaline crab abundances has been used as a as a tool for documenting the biological effects of altered freshwater inflows. Corresponding to recommendation 2, this sampling method has been employed in the Ten Thousand Islands and a single sampling site in the Rookery Bay estuary. The northwestern region of Rookery Bay, among others, needs to be surveyed for potential oyster reef sampling sites and assessment of decapod abundances should resume throughout the estuarine complex. Furthermore, this sampling technique could be expanded to include a suite of invertebrates and fishes inhabiting oyster reefs which may also be useful as indicator taxa.

(4) The Mayan cichlid (*Cichlasoma urophthalmus*) is an introduced species of freshwater fish that is able to tolerate a wide range of salinities, allowing them to invade and become established in most freshwater and estuarine systems in south Florida. Although not collected during trawl surveys in the open waters of Rookery Bay, this species has been observed in ditches and tidal creeks associated with the estuarine system (Schmid, pers. obs.). An inverse relationship between the relative abundance of Mayan cichlids and other native fish species (i.e., high total number Mayan cichlids, low total number other species and vice versa) has been

documented in estuarine habitat of northern Florida Bay. Furthermore, Mayan cichlids were observed competing for spawning sites and predating nests of native fishes (bass and sunfish) in Everglades National Park. The diet of the Mayan cichlid has been described in native habitats of Central America and freshwater habitat in southern Florida; however, information is lacking on food items consumed in non-native estuarine habitats. Potential competitive and trophic interactions of this introduced species need to be investigated to better understand the ecological role and potential effects to native species in the Rookery Bay estuarine complex.

(5) A number of marine sport fish species occur in the nearshore waters of southern Florida, such as the common snook (*Centropomus undecimalis*), tarpon (*Megalops atlanticus*), and redfish/red drum (*Sciaenops ocellatus*), and information is needed to manage and conserve these economically important resources. The mangrove tidal creek/saltmarsh ecotone is the principal habitat for juvenile stages of snook and tarpon, but large portions of this vital habitat have been destroyed by coastal development or the hydrologic characteristics have been modified by watershed alterations in upland areas. A landmark report in 1973 identified brackish tidal creeks and dredged canals in the Ten Thousand Islands region as developmental habitat for juvenile snook. However, three of the 5 sample sites from this former study were located on Henderson Creek, a Rookery Bay tributary, and these were the most productive sites for collecting juvenile snook. Recent reconnaissance of this area found that the urbanization surrounding RBNERR during the last 40 years had modified or eliminated these nursery habitats (Schmid, pers. obs.). Marine sport fish were not well-represented in trawl surveys of the open estuary so other sampling

techniques need to be applied in the tidal creek and salt marsh habitats to assess their ecological relationships in the Rookery Bay complex. Information on juvenile sport fish and their developmental environment is needed to conserve the remaining habitat of these economically-important species and to guide restoration efforts in impacted areas.

(6) The distribution of the diamondback terrapin, *Malaclemys terrapin*, is restricted to brackish coastal waters, making this a potential indicator species for assessing changes in freshwater inflow to estuarine systems. Other than anecdotal observations in the Ten Thousand Islands, there is no information concerning the demographics and ecological relationships of diamondback terrapins in RBNERR.

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Table 1. Taxonomic list of fishes collected in the Rookery Bay estuary during trawling surveys in the 1970s, 1990s, and 2010s.

Class	Order	Family	Scientific name	Common Name
Chondrichthyes	Myliobatiformes	Dasyatidae	*Dasyatis americana*	southern stingray
Chondrichthyes	Myliobatiformes	Dasyatidae	*Dasyatis sabina*	Atlantic stingray
Chondrichthyes	Myliobatiformes	Gymnuridae	*Gymnura micrura*	smooth butterfly ray
Chondrichthyes	Torpediniformes	Narcinidae	*Narcine bancroftii*	lesser electric ray
Actinopterygii	Albuliformes	Albulidae	*Albula vulpes*	bonefish
Actinopterygii	Anguilliformes	Ophichthidae	*Myrophis punctatus-Ophichthus gomesii*	shrimp eel, speckled worm eel
Actinopterygii	Atheriniformes	Atherinopsidae	*Menidia beryllina-Membras martinica*	Inland silverside, rough silverside
Actinopterygii	Aulopiformes	Synodontidae	*Synodus foetens*	lizardfish
Actinopterygii	Batrachoidiformes	Batrachoididae	*Opsanus beta*	toadfish
Actinopterygii	Batrachoidiformes	Batrachoididae	*Porichthys plectrodon*	Atlantic midshipman
Actinopterygii	Beloniformes	Hemiramphidae	*Hyporhamphus unifasciatus*	halfbeak
Actinopterygii	Clupeiformes	Clupeidae		herrings, sardines
Actinopterygii	Clupeiformes	Engraulidae	*Anchoa mitchilli-Anchoa hepsetus*	bay anchovy, striped anchovy
Actinopterygii	Cyprinodontiformes	Fundulidae	*Lucania parva*	rainwater killifish
Actinopterygii	Elopiformes	Elopidae		unid. leptocephalus
Actinopterygii	Gasterosteiformes	Syngnathidae	*Hippocampus erectus*	lined seahorse
Actinopterygii	Gasterosteiformes	Syngnathidae	*Hippocampus zosterae*	dwarf seahorse
Actinopterygii	Gasterosteiformes	Syngnathidae	*Syngnathus louisianae*	chain pipefish
Actinopterygii	Gasterosteiformes	Syngnathidae	*Syngnathus scovelli*	Gulf pipefish
Actinopterygii	Lophiiformes	Ogcocephalidae	*Ogcocephalus cubifrons*	polka dot batfish
Actinopterygii	Mugiliformes	Mugilidae	*Mugil* spp.	mullet
Actinopterygii	Ophidiiformes	Bythitidae	*Gunterichthys longipenis*	gold brotula
Actinopterygii	Perciformes	Blenniidae	*Chasmodes saburrae*	Florida blenny
Actinopterygii	Perciformes	Carangidae	*Chloroscombrus chrysurus*	Atlantic bumper

Table 1.continued

Class	Order	Family	Scientific name	Common Name
Actinopterygii	Perciformes	Carangidae	*Hemicaranx amblyrhynchus*	bluntnose jack
Actinopterygii	Perciformes	Carangidae	*Selene vomer*	lookdown
Actinopterygii	Perciformes	Centropomidae	*Centropomus undecimalis*	common snook
Actinopterygii	Perciformes	Ephippidae	*Chaetodipterus faber*	Atlantic spadefish
Actinopterygii	Perciformes	Gerreidae	*Eucinostomus* spp.	mojarras
Actinopterygii	Perciformes	Gobiidae	*Bathygobius soporator*	frillfin goby
Actinopterygii	Perciformes	Gobiidae	*Ctenogobius boleosoma*	darter goby
Actinopterygii	Perciformes	Gobiidae	*Ctenogobius shufeldti*	freshwater goby
Actinopterygii	Perciformes	Gobiidae	*Gobionellus oceanicus*	sharptail goby
Actinopterygii	Perciformes	Gobiidae	*Gobiosoma bosc-Gobiosoma robustum*	naked goby-code goby
Actinopterygii	Perciformes	Gobiidae	*Gobiosoma longipala*	two-scale goby
Actinopterygii	Perciformes	Gobiidae	*Microgobius gulosus-Microgobius thalassinus*	clown goby, green goby
Actinopterygii	Perciformes	Haemulidae	*Haemulon plumieri*	white grunt
Actinopterygii	Perciformes	Haemulidae	*Orthopristis chrysoptera*	pigfish
Actinopterygii	Perciformes	Lutjanidae	*Lutjanus griseus*	gray/mangrove snapper
Actinopterygii	Perciformes	Lutjanidae	*Lutjanus synagris*	lane snapper
Actinopterygii	Perciformes	Rachcentridae	*Rachycentron canadum*	cobia
Actinopterygii	Perciformes	Scaridae	*Nicholsina usta*	emerald parrotfish
Actinopterygii	Perciformes	Sciaenidae	*Bairdiella chrysoura*	silver perch
Actinopterygii	Perciformes	Sciaenidae	*Cynoscion arenarius*	sand seatrout
Actinopterygii	Perciformes	Sciaenidae	*Cynoscion nebulosus*	spotted seatrout
Actinopterygii	Perciformes	Sciaenidae	*Leiostomus xanthurus*	spot
Actinopterygii	Perciformes	Sciaenidae	*Menticirrus americanus*	southern kingfish
Actinopterygii	Perciformes	Sciaenidae	*Sciaenops ocellatus*	red drum/redfish

Table 1.continued

Class	Order	Family	Scientific name	Common Name
Actinopterygii	Perciformes	Serranidae	*Diplectrum formosum*	sand perch
Actinopterygii	Perciformes	Serranidae	*Mycteroperca microlepis*	gag grouper
Actinopterygii	Perciformes	Serranidae	*Serranus subligarius*	belted sandfish
Actinopterygii	Perciformes	Sparidae	*Archosargus probatocephalus*	sheepshead
Actinopterygii	Perciformes	Sparidae	*Calamus arctifrons*	grass porgy
Actinopterygii	Perciformes	Sparidae	*Lagodon rhomboides*	pinfish
Actinopterygii	Perciformes	Sphyraenidae	*Sphyraena borealis*	northern sennet
Actinopterygii	Perciformes	Stromateidae	*Peprilus paru*	harvestfish
Actinopterygii	Pleuronectiformes	Achiridae	*Achirus lineatus*	lined sole
Actinopterygii	Pleuronectiformes	Achiridae	*Trinectes maculatus*	hogchocker
Actinopterygii	Pleuronectiformes	Cynoglossidae	*Symphurus plagiusa*	blackcheek tonguefish
Actinopterygii	Pleuronectiformes	Paralichthyidae	*Ancylopsetta quadriocellata*	ocellated flounder
Actinopterygii	Pleuronectiformes	Paralichthyidae	*Citharichthys spilopterus-Etropus crossotus*	bay whiff, fringed flounder
Actinopterygii	Pleuronectiformes	Paralichthyidae	*Paralichthys albigutta*	Gulf flounder
Actinopterygii	Scorpaeniformes	Triglidae	*Prionotus scitulus*	leopard searobin
Actinopterygii	Scorpaeniformes	Triglidae	*Prionotus tribulus*	bighead searobin
Actinopterygii	Siluriformes	Ariidae	*Arius felis*	hardhead catfish
Actinopterygii	Siluriformes	Ariidae	*Bagre marinus*	gafftopsail catfish
Actinopterygii	Tetraodontiformes	Diodontidae	*Chilomycterus schoepfi*	striped burrfish
Actinopterygii	Tetraodontiformes	Monacanthidae	*Aluterus schoepfii*	orange filefish
Actinopterygii	Tetraodontiformes	Monacanthidae	*Stephanolepis ciliatus*	fringed filefish
Actinopterygii	Tetraodontiformes	Monacanthidae	*Acanthostracion hispidus*	planehead filefish
Actinopterygii	Tetraodontiformes	Ostraciidae	*Lactophrys quadricornis*	cowfish
Actinopterygii	Tetraodontiformes	Tetraodontidae	*Sphroides nephalus*	southern puffer

Table 2.Abundance of fish taxa collected in Rookery Bay estuary during trawl surveys. Taxa are sorted on total abundance for all surveys.

		Trawl survey dataset			Total	% total
Scientific name	Common Name	1970s	1990s	2010s	abundance	abundance
Eucinostomus spp.	mojarra	7,008	19,371	22,212	48,591	53.27
Lagodon rhomboides	pinfish	10,478	1,342	4,308	16,128	17.68
Anchoa mitchilli-Anchoa hepsetus	bay anchovy, striped anchovy	339	1,707	7,039	9,085	9.96
Orthopristis chrysoptera	pigfish	2,275	2,194	1,424	5,893	6.46
Lutjanus synagris	lane snapper	325	1,653	939	2,917	3.20
Symphurus plagiusa	blackcheek tonguefish	254	638	128	1,020	1.12
Bairdiella chrysoura	silver perch	340	269	366	975	1.07
Cynoscion arenarius	sand seatrout	75	39	458	572	0.63
Microgobius gulosus-Microgobius thalassinus	Clown goby, green goby	27	254	194	475	0.52
Syngnathus scovelli	Gulf pipefish	203	134	84	421	0.46
Citharichthys spilopterus-Etropus crossotus	bay whiff, fringed flounder	161	138	72	371	0.41
Arius felis	hardhead catfish	24	112	233	369	0.40
Leiostomus xanthurus	spot	270	36	26	332	0.36
Prionotus scitulus	leopard searobin	55	217	37	309	0.34
Clupeidae	herrings, sardines	25	216	43	284	0.31
Stephanolepis hispidus	planehead filefish	61	161	56	278	0.30
Menticirrus americanus	southern kingfish	198	20	37	255	0.28
Prionotus tribulus	bighead searobin	136	62	54	252	0.28
Synodus foetens	lizardfish	44	128	62	234	0.26
Achirus lineatus	lined sole	121	91	10	222	0.24
Lutjanus griseus	gray/mangrove snapper	31	122	68	221	0.24
Ogcocephalus cubifrons	polka dot batfish	2	99	110	211	0.23
Gobiosoma bosc-Gobiosoma robustum	naked goby, code goby	74	83	46	203	0.22
Sphroides nephalus	southern puffer	74	85	30	189	0.21
Chilomycterus schoepfi	striped burrfish	46	94	49	189	0.21
Chloroscombrus chrysurus	Atlantic bumper	1	32	152	185	0.20
Paralichthys albigutta	Gulf flounder	55	60	34	149	0.16

Table 2.continued.

Scientific name	Common Name	Trawl survey dataset 1970s	1990s	2010s	Total abundance	% total abundance
Archosargus probatocephalus	sheepshead	75	54	12	141	0.15
Opsanus beta	toadfish	18	49	31	98	0.11
Syngnathus louisianae	chain pipefish	32	38	27	97	0.11
Chaetodipterus faber	Atlantic spadefish	22	25	37	84	0.09
Myrophis punctatus-Ophichthus gomesii	shrimp eel, speckled worm eel	14	52	12	78	0.09
Cynoscion nebulosus	spotted seatrout	12	31	10	53	0.06
Ctenogobius boleosoma	darter goby	0	38	0	38	0.04
Diplectrum formosum	sand perch	11	22	3	36	0.04
Haemulon plumieri	white grunt	30	0	0	30	0.03
Bagre marinus	gafftopsail catfish	6	9	12	27	0.03
Acanthostracion quadricornis	cowfish	1	5	14	20	0.02
Gymnura micrura	smooth butterfly ray	10	5	3	18	0.02
Dasyatis sabina	Atlantic stingray	1	9	6	16	0.02
Hippocampus zosterae	dwarf seahorse	13	2	1	16	0.02
Sciaenops ocellatus	red drum/redfish	15	0	0	15	0.02
Gunterichthys longipenis	gold brotula	3	4	7	14	0.02
Calamus arctifrons	grass porgy	1	6	6	13	0.01
Hemicaranx amblyrhynchus	bluntnose jack	0	0	12	12	0.01
Bathygobius soporator	frillfin goby	1	9	0	10	0.01
Ancylopsetta quadriocellata	ocellated flounder	0	8	1	9	0.01
Nicholsina usta	emerald parrotfish	0	6	1	7	0.01
Trinectes maculatus	hogchocker	7	0	0	7	0.01
Gobionellus oceanicus	sharptail goby	0	6	0	6	0.01
Hippocampus erectus	lined seahorse	3	0	2	5	0.01
Ctenogobius shufeldti	freshwater goby	5	0	0	5	0.01
Stephanolepis ciliatus	fringed filefish	3	2	0	5	0.01
Narcine bancroftii	lesser electric ray	4	0	0	4	<0.01

Table 2.continued.

Scientific name	Common Name	Trawl survey dataset 1970s	1990s	2010s	Total abundance	% total abundance
Mycteroperca microlepis	gag grouper	4	0	0	4	<0.01
Menidia beryllina-Membras martinica	Inland silverside, rough silverside	1	0	2	3	<0.01
Mugil spp.	mullet	0	0	3	3	<0.01
Selene vomer	lookdown	0	0	3	3	<0.01
Lucania parva	rainwater killifish	2	0	0	2	<0.01
Elopidae	unid. leptocephalus	1	0	1	2	<0.01
Chasmodes saburrae	Florida blenny	1	1	0	2	<0.01
Serranus subligarius	belted sandfish	0	2	0	2	<0.01
Aluterus schoepfii	orange filefish	0	0	2	2	<0.01
Centropomus undecimalis	common snook	1	0	1	2	<0.01
Dasyatis americana	southern stingray	0	0	1	1	<0.01
Albula vulpes	bonefish	0	1	0	1	<0.01
Porichthys plectrodon	Atlantic midshipman	0	1	0	1	<0.01
Hyporhamphus unifasciatus	halfbeak	0	1	0	1	<0.01
Gobiosoma longipala	two-scale goby	1	0	0	1	<0.01
Rachycentron canadum	cobia	1	0	0	1	<0.01
Sphyraena borealis	northern sennet	0	1	0	1	<0.01
Peprilus paru	harvestfish	0	0	1	1	<0.01

Table 3. Analyses of each Rookery Bay fisheries datasets with one-way ANOSIM for year count (Year 1 vs. Year 2) and two-way crossed ANOSIM for sampling stations and seasons (wet vs. dry). Significance levels are given in parentheses.

	One-way	Two-way crossed	
Dataset	Year count	Station	Season
1970s	0.043 (0.012)	0.229 (0.0001)	0.341 (0.0001)
1990s	0.024 (0.054)	0.145 (0.0001)	0.423 (0.0001)
2010s	0.038 (0.031)	0.103 (0.0001)	0.573 (0.0001)

Table 4. Pairwise ANOSIM comparisons of fish communities at Rookery Bay sampling stations for each of the databases. T1 – Station 1, T2 – Station 2, T3 – Station 3, and T4 – Station 4. Highly significant differences are indicated in bold.

1970s			
	T1	T2	T3
T2	**0.353 (0.0001)**		
T3	0.111 (0.015)	**0.353 (0.0001)**	
T4	**0.304 (0.0001)**	0.053 (0.097)	**0.217 (0.0003)**

1990s			
	T1	T2	T3
T2	0.163 (0.003)		
T3	0.101 (0.022)	0.039 (0.136)	
T4	0.056 (0.108)	**0.262 (0.0001)**	**0.245 (0.0005)**

2010s			
	T1	T2	T3
T2	0.122 (0.015)		
T3	-0.007 (0.505)	0.169 (0.001)	
T4	0.062 (0.095)	**0.273 (0.0002)**	0.001 (0.423)

Table 5. Results of SIMPER analysis showing the most influential fish taxa contributing to the dissimilarity between seasons of each of the Rookery Bay datasets.

Dataset and fish taxa	Avg. abundance (square root transformation)		Percent contrib. to dissimilarity
1970s	Wet	Dry	
Lagodon rhomboides	1.05	8.35	16.40
Eucinostomus spp.	9.35	5.02	16.12
Orthopristis chrysoptera	0.84	4.54	10.18
Lutjanus synagris	1.73	0.76	4.50
Anchoa mitchilli-Anchoa hepsetus	0.52	1.50	4.23
1990s	Wet	Dry	
Eucinostomus spp.	17.45	7.29	22.04
Orthopristis chrysoptera	1.03	4.57	8.05
Lutjanus synagris	4.79	1.58	7.69
Lagodon rhomboides	1.48	3.47	6.45
Anchoa mitchilli-Anchoa hepsetus	3.02	3.38	6.09
2010s	Wet	Dry	
Eucinostomus spp.	18.24	5.84	26.34
Lagodon rhomboides	0.98	7.66	13.64
Anchoa mitchilli-Anchoa hepsetus	6.68	7.59	10.51

Table 6. Results of the BVSTEP routine showing the subset of fish taxa that best characterize the overall fish community structure in the Rookery Bay estuary for the corresponding dataset. Spearman's rank correlation coefficient (ρ) and the number of restarts for each subset are given in parentheses.

1970s (ρ=0.956 and 53 restarts)	1990s (ρ =0.953 and 15 restarts)	2010s (ρ =0.950 and 100 restarts)
Anchoa mitchilli-Anchoa hepsetus	*Anchoa mitchilli-Anchoa hepsetus*	*Anchoa mitchilli-Anchoa hepsetus*
Bairdiella chrysoura		
Citharichthys spilopterus-Etropus crossotus		
Eucinostomus spp.	*Eucinostomus* spp.	*Eucinostomus* spp.
Lagodon rhomboides	*Lagodon rhomboides*	*Lagodon rhomboides*
Lutjanus synagris	*Lutjanus synagris*	
	Microgobius gulosus-Microgobius thalassinus	
Menticirrus americanus		
	Ogcocephalus cubifrons	
Orthopristis chrysoptera	*Orthopristis chrysoptera*	*Orthopristis chrysoptera*
	Prionotus scitulus	
Symphurus plagiusa	*Symphurus plagiusa*	

Table 7. Results of two-way SIMPER analysis showing the most influential fish taxa contributing to the dissimilarity between studies and seasons for the combined Rookery Bay dataset averaged by study, station, and season.

Data treatment and fish taxa	Avg. abundance (square root transformation)		Percent contrib. to dissimilarity
Temporal	1970s	1990s	
Eucinostomus spp.	7.19	12.35	18.77
Lagodon rhomboides	4.70	2.47	10.99
Anchoa mitchilli-Anchoa hepsetus	1.01	3.18	7.76
Lutjanus synagris	1.24	3.18	6.72
Orthopristis chrysoptera	2.69	2.81	4.75
	1970s	2010s	
Anchoa mitchilli-Anchoa hepsetus	1.01	7.12	20.33
Eucinostomus spp.	7.19	12.04	16.76
Lagodon rhomboides	4.70	4.32	11.56
Orthopristis chrysoptera	2.69	2.03	5.00
	1990s	2010s	
Anchoa mitchilli-Anchoa hepsetus	3.18	7.12	16.87
Lagodon rhomboides	2.47	4.32	11.42
Eucinostomus spp.	12.35	12.04	7.37
Orthopristis chrysoptera	2.81	2.03	6.06
Lutjanus synagris	3.18	2.46	4.35
Symphurus plagiusa	1.88	0.79	4.16
Seasonal	Wet	Dry	
Eucinostomus spp.	15.02	6.04	25.48
Lagodon rhomboides	1.17	6.49	15.31
Orthopristis chrysoptera	0.87	4.16	9.73
Lutjanus synagris	3.39	1.20	6.03
Anchoa mitchilli-Anchoa hepsetus	3.40	4.14	4.22

Table 8. Average abundance for the fish taxa identified in the SIMPER analyses as contributing the most to temporal and seasonal differences in the fish communities in Rookery Bay. For seasons, EW – early wet (Jun-Aug), LW – late wet (Sep-Nov), ED – early dry (Dec-Feb), and LD – late dry (Mar-May). Highest abundance for a given species and dataset are indicated in bold.

	Fish taxa				
Dataset and season	*Eucinostomus* spp.	*Lagodon rhomboides*	*Orthopristis chrysoptera*	*Lutjanus synagris*	*Anchoa mitchili-Anchoa hepsetus*
1970s					
EW	93.6	12.7	11.5	3.1	0.5
LW	**123.8**	0.4	0.0	**7.2**	3.3
ED	56.0	149.5	10.0	2.8	1.3
LD	18.5	**274.0**	**73.3**	0.5	**9.1**
1990s					
EW	**440.2**	13.0	6.3	**38.7**	19.6
LW	231.4	0.9	0.8	19.9	12.3
ED	77.7	18.9	9.8	8.9	14.8
LD	64.3	**24.7**	**75.3**	2.1	**25.7**
2010s					
EW	**648.6**	4.5	3.5	**18.8**	30.9
LW	188.2	0.3	0.1	17.4	90.8
ED	11.0	83.0	10.5	2.8	**126.4**
LD	131.8	**92.0**	**45.4**	1.7	47.7

Figure 1. Map of western Collier County, Florida showing the location of trawl sampling stations (red star) in the Rookery Bay estuarine complex.

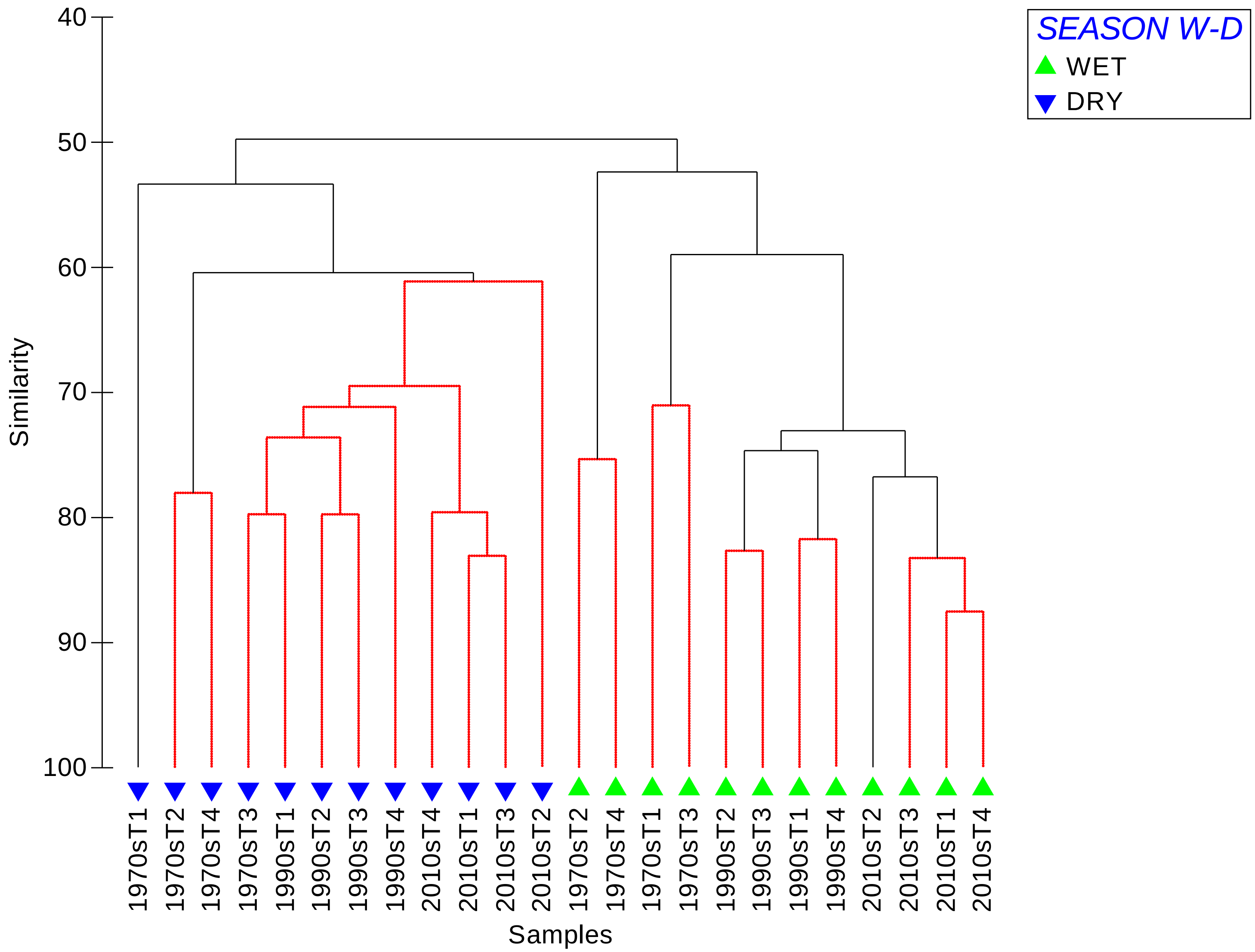

Figure 2. Bray-Curtis similarity dendogram for fish communities collected during trawl surveys in Rookery Bay estuary. Black line indicates significantly different groupings identified by SIMPROF whereas groups with red line are not significantly different.

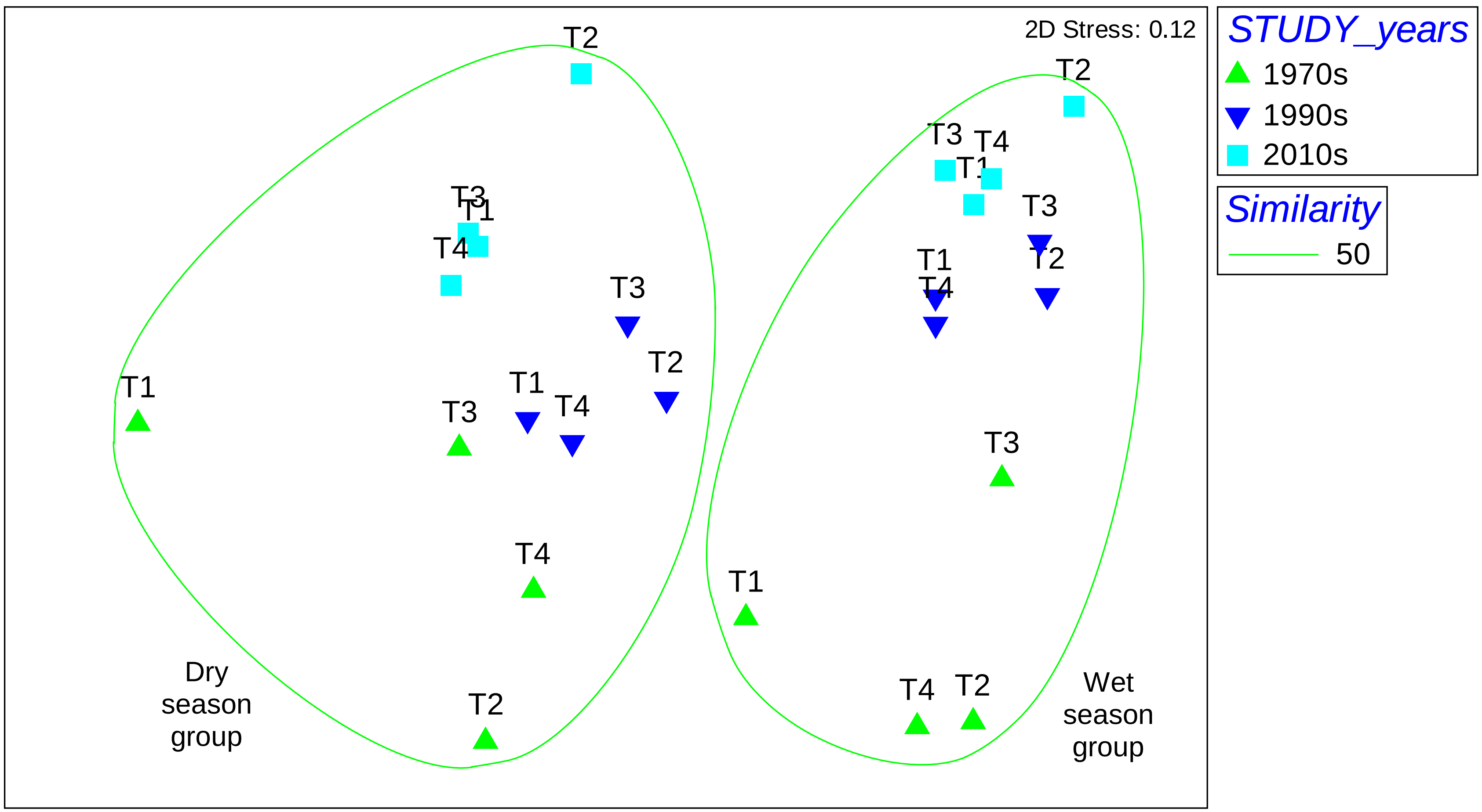

Figure 3. MDS ordination plots for fish communities collected during trawl surveys in Rookery Bay estuary.