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# *A comparison of current and historical fish assemblages in a Caribbean island estuary: conservation value of historical data*

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ABSTRACT

1. Historical data are often one of the only resources available for documenting and assessing causes of environmental change, particularly in developing regions where funding for ecological studies is limited. In this paper, previously unpublished data from a year-long study (1977) of the fish community of the Espiritu Santo estuary are presented. This dataset is among the oldest and most extensive surveys of a Caribbean island estuarine fish community.
2. A comparison of these historical data with data collected in June and July 2004 using identical sampling methods allowed description of potential long-term changes in the fish community, identification of vulnerable species, and assessment of potential drivers of change.
3. Results strongly suggest a decline in species richness and abundance in the Espiritu Santo estuarine fish community, with greater declines in freshwater-tolerant than marine or euryhaline species. Declines in freshwater inflow to the estuary, due to large-scale upstream water abstractions for municipal use, have increased since the initial 1977 survey.
4. This is the first study to examine long-term change in the fish community of a tropical island estuary. Additional research and conservation efforts are needed to understand mechanisms of change and to protect Caribbean island estuarine fish communities.


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KEY WORDS: estuarine fishes; freshwater fishes; long-term change; watershed change; freshwater diversion

## INTRODUCTION

Historical observations, even if limited or qualitative, often provide one of the only resources for documenting and assessing causes of ecosystem change. Use of historical data is particularly important in developing regions with limited funding for ecological studies and few long-term datasets. This approach, however, can be challenging because historical studies are often characterized by missing or unclear records. In addition, the original data collector may be difficult to locate, potentially leading to methodological uncertainties about the original study. Several studies have, nonetheless, effectively documented species

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declines or extinctions via comparison of current and historical data. For example, Drayton and Primack (1996) found large changes in the plant community of a small Boston woodland over a century; Kattan *et al.* (1994) identified local extinctions and bird species declines in Columbia over 80 years; and Reinthal and Stiassny (1991) reported losses of freshwater fish species in Madagascar, coinciding with increases in exotic species. These examples illustrate that even when historical data are limited in scope, they are valuable for identifying species declines, characteristics of vulnerable species, and environmental drivers of change (Patton *et al.*, 1998). Early recognition of species declines is crucial for preventing extinctions and reducing long-term costs of conservation actions.

Fish communities of Caribbean island estuaries have received little study due to lack of resources and governmental support (Stoner, 1986; Blaber, 2002; Rivera-Monroy *et al.*, 2004). Appropriate conservation and management actions are difficult without basic data describing these communities. Such data are crucial: a study of North American marine and estuarine fish species at risk suggests that Caribbean island fish may be particularly vulnerable to environmental change (Musick *et al.*, 2001). Three of the five geographic localities in North America, noted to have a high number of species at risk, were located in southern Florida, a region that shares many species with Caribbean islands. In addition, migratory anadromous and amphidromous species were identified as particularly vulnerable due to habitat degradation (Musick *et al.*, 2001). This finding raises further concern for Caribbean islands such as Puerto Rico, where all native freshwater fish are amphidromous.

In this paper, previously unpublished historical data from a year-long, 1977 study of the Espiritu Santo fish community (conducted by I. Corujo Flores) are presented and compared with data collected using identical sampling methods in June and July 2004. In 1977, the Espiritu Santo estuary was considered one of the least disturbed estuaries in Puerto Rico; however, in the last 30 years its watershed has been affected by increasing population growth and urbanization (Ramos Gonzalez, 2001; Ortiz-Zayas and Scatena, 2004). The 1977 fish community dataset presented here is among the oldest and most extensive from a Caribbean island estuary. As such, these data provide a rare opportunity to document 'baseline' conditions in the Espiritu Santo estuary, examine potential long-term changes in its fish community, and identify vulnerable species and drivers of species declines.

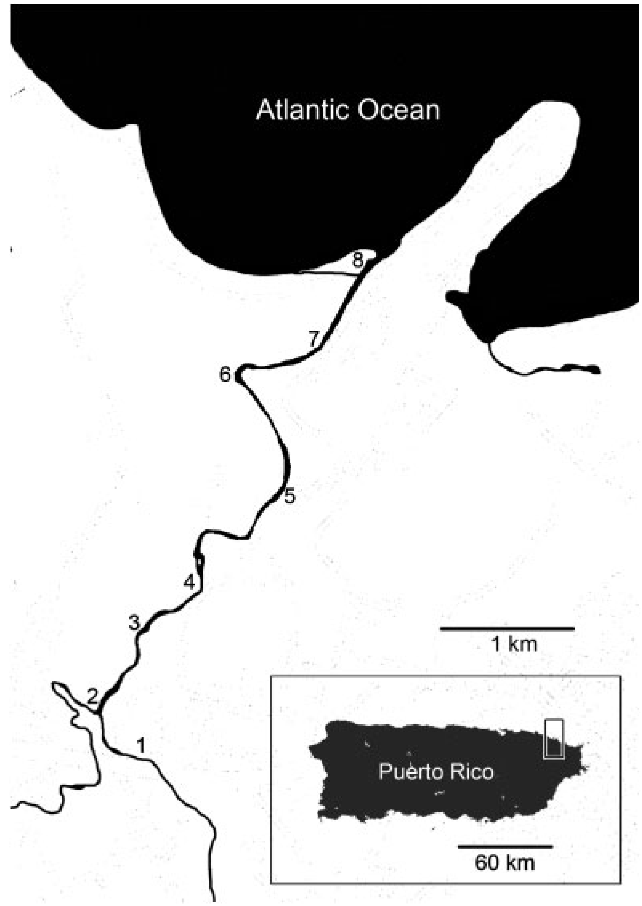

Figure 1. Espiritu Santo estuary, Puerto Rico showing locations of sampling stations for 1977 and 2004 fish community surveys.

## METHODS

### Study site

The Espiritu Santo estuary is adjacent to the town of Rio Grande in north-eastern Puerto Rico (Figure 1). Puerto Rico's north-eastern estuaries, including the Espiritu Santo, are riverine type estuaries that, in comparison to lagoonal or deltaic estuaries, are characterized by a high ratio of freshwater to tidal inflow, a low width to depth ratio, and a high perimeter to area ratio (Morris and Hu, 1995). The estuary is relatively small extending less than 7 km inland, ranging from 12 to 55 m in width and 1 to 6 m in depth, and with a drainage area of approximately 25 $km^2$. Its substrate is composed of sand and gravel, with some areas of cobble in its upper reaches and a thick layer of organic detritus in the mid and lower reaches. The estuary is bordered by pasture lands in the upper reaches and by mangrove wetlands in the lower reaches. Long-term annual flow to the estuary averages $1.68\,m^3\,s^{-1}$ most of which reaches the estuary during large flood events. Owing to the high elevational gradient of its drainage basin, flow through the estuary is visible except during periods of very low discharge. The estuary is strongly and permanently stratified (at approximately 0.5 m in depth)



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with a distinct salt wedge. Flooding may disrupt this stratification, though generally for less than 24 h. Turbidity ranges from an average of 15 NTU during normal flow to more than 50 NTU after storm events. Tidal amplitude in the region is low ($<1$ m).

The Espiritu Santo is the only estuary in Puerto Rico's north-eastern coast that remains open to the ocean year-round, with no sandbar formation at its mouth. In addition, an extensive reef system lies just outside the mouth of the estuary. As a result of these two characteristics, the Espiritu Santo hosts many marine migrants and has unusually high fish species richness for the region (Negron and Cintron, 1979). The Espiritu Santo is also one of the most protected estuaries in Puerto Rico. The Espiritu Santo river originates in Luquillo Experimental Forest (LEF) at an elevation of approximately 1000 m and the estuary is included in the Espiritu Santo Reserve. The National Forest designation has protected much of the Espiritu Santo watershed from development. In addition, because of the protection conferred by its reserve status, the Espiritu Santo estuary, unlike most of Puerto Rico's estuaries, has retained some of its mangrove wetlands. The areas surrounding the reserve, however, are primarily urban and suburban (Ramos Gonzalez, 2001). There is no commercial and only limited recreational fishing in the estuary although a small marina is located on the estuary and commercial fishermen use the estuary for boat access to offshore reefs. The estuary is also used for kayaking and recreation.

## Changes to the Espiritu Santo watershed between 1977 and 2004

Despite its reserve status, the Espiritu Santo estuary is threatened by urbanization, loss of mangroves within the reserve, and upstream water diversions. Water diversions are a threat to estuaries throughout Puerto Rico and particularly so in the densely populated north-east where water demand is high and groundwater is limited (March *et al*., 2003; Ortiz-Zayas and Scatena, 2004). The Espiritu Santo river is the most heavily diverted river in the LEF (Crook *et al*., 2007). At least ten water intakes, most of which were built within the past 30 years, are currently located within the Espiritu Santo basin. These intakes extract more than 20% of the Espiritu Santo's annual runoff. Because most of the runoff occurs during large storm events, the day-to-day impact is even greater with 82% of median flow withdrawn from the river (Crook *et al*., 2007).

Upstream water diversions have greatly increased since the Espiritu Santo estuary was designated as a reserve. The largest water intake on the river was constructed in 1984, after the estuary was given reserve status. Withdrawals at this intake account for more than twice the total of all the other intakes combined (Crook *et al*., 2007). During drought periods, all fresh water in the stream is diverted at this intake. On such occasions, marine fish species have been observed directly below the dam, located more than 1 km above the head of the estuary (March *et al*., 2003). Two changes to the estuary and near shore marine environment may have also influenced the Espiritu Santo salinity patterns. Dredging, from the middle to the mouth of the estuary, has occurred for sand mining and to facilitate boat traffic from the estuary to ocean fishing grounds. In addition, a portion of the reef located near the mouth of the estuary was removed to facilitate boat traffic from the estuary to marine fishing grounds. These changes may have increased the penetration of the salt wedge into the estuary.

Large-scale shifts in land use have also occurred in north-eastern Puerto Rico since the late 1970s. Ramos Gonzalez (2001) evaluated land-use change in north-eastern Puerto Rico between 1978 and 1995, documenting an almost completed replacement of agricultural lands with forest and shrub cover in the uplands, and urban and suburban development in the coastal plains. Eighty-five percent of the new development between 1978 and 1995 occurred in the lowlands and coastal plains region (Ramos Gonzalez, 2001). Urbanization in the basin has likely altered sediment inputs to the estuary (Edgar and Barrett, 2000) and has encroached on mangrove stands surrounding the Espiritu Santo estuary (I. Corujo Flores, personal observation).

Many improvements have been made to the water quality of the Espiritu Santo estuary since the 1970s. Point source pollution has decreased because of improvements in sewage treatment and water quality regulations. In the late 1970s, the estuary received 0.8 million gallons day$^{-1}$ of discharge from a secondary sewage treatment plant. Fish sampling near the sewage discharge point was often difficult in 1977 because gill nets frequently became clogged with toilet paper (I. Corujo Flores, personal observation). Sewage is no longer discharged directly into the estuary, although failure of the treatment system resulted in sewage overflow to the estuary on several occasions in 2004 (K. Smith, personal observation). The decline of agriculture in the region has likely reduced fertilizer and pesticide runoff to the estuary. Water hyacinth (*Eichhornia crassipes*), which covered large portions of the estuary in 1977, was absent from the estuary in 2004 possibly owing to these reduced nutrient inputs.

## Field sampling

### *1977 sampling*

Fish were collected monthly by I. Corujo Flores between February 1977 and January 1978 (referred to as 1977 sampling) from eight approximately evenly spaced sampling



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stations along the salinity gradient (Figure 1). On each sampling event, four experimental $100 \times 8$ ft nylon sinking gill nets, each of a single mesh size ($\frac{1}{2}$, 1, 2, and 3 inches square), were deployed to capture fish at each station. Each net was anchored to the shore and deployed at a 45° angle sloped towards the freshwater flow. The 2″ and 3″ nets were placed on opposite shores at extremes of the sampling station and the $\frac{1}{2}''$ and 1″ nets were placed on opposite shores between the larger nets. Nets were set for 1.5 hours between 0700 and 1100 h. Dip nets were used to collect smaller fish along the shores. All fish were weighed and measured for total and standard lengths.

At each station, water samples were taken after each sampling event from the middle of the channel, 0.25 m below the surface and 0.25 m above the estuary floor. Samples were stored in polyethylene bottles and returned to the laboratory where salinity was determined with a Bausch and Lomb temperature compensated refractometer. Standard MohR titration with silver nitrate ($AgNO_3$) was used when salinity levels were under the detection limits of the refractometer. Temperature was recorded *in situ* with a Kemmerer water sampling bottle equipped with a calibrated thermometer.

### *2004 sampling*

In June and July of 2004, the same eight stations (Figure 1) were sampled once per month also between 0700 and 1100 h with identical gear and methods as in 1977. To ensure consistency between 1977 and 2004 sampling, I. Corujo Flores re-delineated the 1977 sampling stations and trained K. Smith in sampling methods. To increase the sample size and capture of crepuscular fish, additional night sampling (between 1900 and 2300 h) was carried out at least once per month at all sampling stations. Night sampling effectively doubled the 2004 sampling effort over the 1977 sampling effort. During each 2004 sampling event, surface (at −0.25 m) and bottom (at 0.25 m above the substrate) temperature, salinity, dissolved oxygen, and turbidity were recorded from the middle of the channel with a Hydrolab Quanta (Hydrolab Inc.).

### *1977 and 2004 comparisons*

Raw data from the 1977 study were lost when the Center for Energy and Environment, where they were stored, was closed. Detailed summaries of the fish community and environmental conditions were preserved in a Masters thesis (Corujo Flores, 1980). These data are used to describe the 1977 fish community and environmental conditions. After summarizing the 1977 data, species richness, diversity, abundance, and community composition are compared for 1977 and 2004 using identical subsets of the 1977 and 2004 data—June and July day sampling (further referred to as base sampling). For some comparisons, additional data such as 2004 night sampling and year long 1977 data are presented alongside base sampling comparisons. It is important to note that many statistical analyses could not be applied because the 1977 data were preserved only in summary form.

The number of species (observed species richness) detected during 1977 and 2004 base sampling was compared. Because observed species richness may not reflect the true number of species present in an area (Colwell and Coddington, 1994), estimated species richness (the Chao1 estimator) was calculated using EstimateS Version 7.5 (Colwell, 2005). The Chao1 estimator is defined as:

$$\hat{S}_{\text{Chao1}} = S_{\text{obs}} + [f^2(1)/2f(2)]$$

where $S_{\text{obs}}$ is the observed number of species, $f(1)$ is the observed number of singletons (only a single individual is observed), and $f(2)$ is the observed number of duplicates. Because of potential differences between species richness estimators we also examined results of the ACE and Chao2 estimators, also calculated with EstimateS, to ensure that trends did not vary between estimators. Lastly, 1977 (day only) observed and estimated species richness was compared with both 2004 day and 2004 day plus night sampling.

A comparison of species diversity (Fisher's Alpha) for 1977 and 2004 base sampling was undertaken. This index, also calculated with EstimateS, was defined as:

$$S = \alpha \ln(1 + N/\alpha)$$

where $N$ is the number of individuals sampled and $S$ is the number of species in the sample. Results from two other diversity indices, the Shannon and Simpson diversity indices, were also calculated to ensure that results did not differ between indices.

Total catch and catch per effort for 1977 and 2004 base sampling was also compared. Because the 1977 data were available only in summary form, catch per effort is presented as the number of fish collected in each month averaged across the eight sampling stations. Catch per effort for 1977 and 2004 base sampling was compared and then put in the context of catch per effort for the entire 12 months sampled in 1977. To illustrate differences in catches of individual species, total catch by species in 1977 versus 2004 is also plotted.

To examine changes in species abundance in the context of their environmental tolerances, information on the salt tolerance and resilience of each species was collected from the FishBase database (Froese and Pauly, 2000). Species were classified by salt tolerance as either *freshwater-oriented* (reported as occurring in freshwater or freshwater and brackish habitats), *marine-oriented* (occurring in marine and brackish habitats), or *euryhaline* (freshwater, brackish, and marine habitats). The relative abundance of species in each



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salinity and resilience category was compared for 1977 and 2004 base sampling. It was predicted that given increased freshwater diversions upstream of the estuary, fewer freshwater-oriented than marine or euryhaline species would be redetected in 2004. Minimum, maximum, and average surface and bottom salinity at high and low tide at each sampling station was also calculated and compared for 1977 and 2004. Fish base resilience categorizations were either high, medium, or low based on reproductive capacity and ability to withstand and recover from exploitation or disturbance (Froese and Pauly, 2000). Changes in the relative abundance of species in each resilience category might indicate changes in estuarine conditions or offshore exploitation. Diet and habitat preference descriptions were not available for all species, so analysis of these factors was not possible.

## RESULTS

### Description of historical (1977) fish community

The year-long, 1977 survey yielded 30 families and 60 species of fish (Table 1), a high species richness for the region (Negron and Cintron, 1979). The majority of species were represented by only a few individuals. Two-thirds of the species comprised less than 1% of the total number of individuals in 1977. Only six species represented more than 5% of the catch. The most common species, *Eleotris pisonis*, comprised only 12% of the total number of individuals captured in 1977. The two most common families, Eleotridae and Clupeidae, comprised 28% and 10% of the catch respectively (Table 1).

Only four species, *E. pisonis*, *Gobiomorus dormitor*, *Mugil curema* and *Microphis brachyurus*, were captured in all 12 months of the study (Table 1), and 20% of the species were residents (i.e. collected in at least 7 out of 12 months). The majority of species (42%) were transients (i.e. collected in the estuary in only one or two non-consecutive months). The remaining 37% of the species were cyclical or regular visitors (i.e. those using the estuary 3 to 6 months out of the year or for two consecutive months).

The majority of species were found in only a few of the sampling stations (Table 1). Half of the species were found in only one or two of the eight stations and 15 of these species were collected from only one sampling station. Only four species (*Centropomus ensiferus*, *Opisthonema oglinum*, *Eugerres plumieri*, *Bairdiella ronchus*) were found at all stations and only eight species were found in more than six of the eight stations.

### The 2004 fish community

The June and July 2004 base sampling survey yielded 16 families and 19 species (Table 2). As in 1977, most species were represented by only a few individuals. Only four species, *O. oglinum* (9.3%), *Lutjanus jocu* (7.0%), *M. curema* (11.7%), and *M. brachyurus* (18.6%) comprised over 5% of the base sampling catch. Most species were captured at only one or two stations and none were captured at over four stations. An additional eight species were captured during night sampling for a total of 27 species captured in 2004. *Caranx latus* (5.6%), *Centropomus pectinatus* (8.3%), *O. oglinum* (7.0%), *Polydactylus virginicus* (8.3%), and *B. ronchus* (11.1%) were most common in 2004 day and night sampling (Table 2).

### 1977 and 2004 comparisons

1977 base sampling yielded 15 more species than 2004 base sampling. Despite identical sampling methods and effort, 34 species were collected in 1977 while only 19 species were detected in 2004. The 1977 *observed* species richness was higher than 2004 *estimated* species richness. In addition, the 1977 *day* sampling species richness was greater than the 2004 *day and night* sampling species richness (Figure 2). Species diversity in 1977 (Fisher's Alpha = 14.2, SD = 1.9), however, was not significantly greater than 2004 diversity (13.0, SD = 3.3). These trends were consistent among different estimators of species richness and diversity.

Fish abundance (catch) was also greater in 1977 (Figure 3). Catch per effort was low and highly variable across all sampling months and years; however, catch per effort in June and July of 2004 was lower than in all 12 months sampled in 1977. Because the 1977 data were summed by month and station, it was not possible to apply statistical analyses to these comparisons. It was also not possible to assess changes in biomass because size information collected in 1977 was not retained for all species.

Figure 4, comparing species abundances between 1977 and 2004, illustrates that most species were more abundant in 1977. Several species commonly detected in 1977 (e.g. *C. ensiferus*, *Trichiurus lepturus* and *Anchovia clupeoides*) were not redetected or were detected only in low numbers (e.g. *D. rhombeus*) in 2004. Only four species found in 1977 were more abundant in 2004 (*O. oglinum, L. jocu, Selene vomer* and *Archosargus rhomboidalis*) and another five species that were not detected in 1977 were represented by one individual in 2004. Exotic species were rare in the Espiritu Santo both in 1977 and 2004. *Oreochromis mossambicus*, the only known exotic species found in 1977, decreased in relative abundance from 3.5% of total catch in 1977 to 1.4% in 2004.

Freshwater-tolerant species showed greater declines than marine species. Only 25% of freshwater-oriented species collected in 1977 were redetected in 2004. In comparison, 53% and 54% of marine and euryhaline-oriented species, respectively, were redetected in 2004. Of the 10 new species detected in 2004 (including night sampling), six were marine-oriented and four euryhaline-oriented but none were



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Table 1. Relative abundance, locations (stations), and seasons (months) of fish captured in the Espiritu Santo estuary, Puerto Rico in 1977. Stations refer to the sampling stations where fish were captured. 'Transient' refers to species collected in the estuary in only one or two non-consecutive months. 'Visitor' refers to species collected in the estuary for three to six months or for two consecutive months. Species collected in seven or more months are classified as 'resident'

| Family | Relative abundance | Species | Relative abundance | Stations | Months | Estuary use |
|---|---|---|---|---|---|---|
| Achiridae | 0.16 | *Achirus lineatus* | 0.16 | 5 | 4, 5 | visitor |
| Anguillidae | 2.79 | *Anguilla rostrata* | 2.79 | 1, 2, 3, 5, 6 | 1, 11 | transient |
| Belonidae | 0.24 | *Strongylura timucu* | 0.24 | 1, 6 | 5, 8, 11 | visitor |
| Bleniidae | 1.67 | *Lupinoblennius dispar* | 1.67 | 5, 6, 7 | 4, 8, 9, 11, 12 | visitor |
| Carangidae | 2.63 | *Caranx hippos* | 0.24 | 6, 7, 8 | 2, 6, 7 | visitor |
| Carangidae | | *Caranx latus* | 1.19 | 1, 2, 3, 5, 6, 7, 8 | 2, 4, 5, 6, 7, 8, 9, 10, 11 | resident |
| Carangidae | | *Chloroscombrus chrysurus* | 0.88 | 3, 4, 6, 7, 8 | 2, 3, 4, 5, 6, 7 | visitor |
| Carangidae | | *Selene vomer* | 0.16 | 7, 8 | 4, 5 | visitor |
| Carangidae | | *Trachinotus goodei* | 0.16 | 4, 7 | 5, 7 | transient |
| Centropomidae | 4.38 | *Centropomus ensiferus* | 2.31 | 1, 2, 3, 4, 5, 6, 7, 8 | 1, 2, 3, 4, 5, 6, 7, 8, 10, 11 | resident |
| Centropomidae | | *Centropomus pectinatus* | 0.16 | 3, 4 | 8 | transient |
| Centropomidae | | *Centropomus undecimalis* | 1.91 | 1, 2, 3, 4, 5, 6 | 2, 3, 4, 5, 6, 7, 9, 10, 11 | resident |
| Cichlidae | 1.35 | *Oreochromis mossambicus* | 1.35 | 3, 4, 5, 7 | 1, 2, 3, 5, 6, 7, 10, 11, 12 | resident |
| Clupeidae | 10.35 | *Harengula humeralis* | 0.32 | 8 | 12 | transient |
| Clupeidae | | *Opisthonema oglinum* | 10.03 | 1, 2, 3, 4, 5, 6, 7, 8 | 6 | transient |
| Cynoglossidae | 0.08 | *Symphurus plagiusa* | 0.08 | 5 | 2 | transient |
| Eleotridae | 28.03 | *Dormitator maculates* | 9.16 | 1, 2, 3, 4, 5, 6, 7 | 1, 3, 6, 8, 11, 12 | visitor |
| Eleotridae | | *Eleotris pisonis* | 11.54 | 1, 2, 3, 4, 5, 6 | 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12 | resident |
| Eleotridae | | *Gobiomorus dormitor* | 7.32 | 1, 2, 3, 4, 5 | 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12 | resident |
| Elopidae | 0.24 | *Elops saurus* | 0.24 | 2, 4, 8 | 2, 4, 12 | visitor |
| Engraulidae | 6.45 | *Anchoa hepsetus* | 0.40 | 7 | 5 | transient |
| Engraulidae | | *Anchovia clupeoides* | 2.79 | 2, 5, 6, 7 | 2, 4, 5, 6, 7, 9 | visitor |
| Engraulidae | | *Cetengraulis edentulus* | 3.26 | 1, 2, 3, 4, 5, 6, 8 | 6 | transient |
| Ephippidae | 0.08 | *Chaetodipterus faber* | 0.08 | 6 | 3 | transient |
| Gerreidae | 6.21 | *Diapterus rhombeus* | 3.34 | 2, 3, 4, 5, 6, 8 | 1, 2, 3, 4, 5, 6, 7, 9, 11 | resident |
| Gerreidae | | *Diapterus auratus* | 0.24 | 3 | 8, 10 | transient |
| Gerreidae | | *Ulaema lefroyi* | 0.08 | 3 | 7 | transient |
| Gerreidae | | *Eucinostomus melanopterus* | 0.16 | 2, 4 | 7, 10 | transient |
| Gerreidae | | *Eugerres plumieri* | 1.75 | 1, 2, 3, 4, 5, 6, 7, 8 | 2, 3, 4, 5, 6, 8, 9, 11, 12 | resident |
| Gerreidae | | *Gerres cinereus* | 0.64 | 1, 2, 3, 5 | 2, 6, 7, 11 | visitor |
| Gobiidae | 5.41 | *Awaous tajasica* | 0.16 | 1 | 8, 10 | transient |
| Gobiidae | | *Bathygobious soporator* | 2.31 | 5, 6, 7, 8 | 1, 4, 7, 8, 9, 10, 11, 12 | resident |
| Gobiidae | | *Ctenogobius boleosoma* | 0.72 | 4, 5, 7 | 1, 5, 6, 8, 9, 10 | visitor |
| Gobiidae | | *Gobionellus oceanicus* | 0.08 | 2 | 5 | transient |
| Gobiidae | | *Gobiosoma spes* | 2.15 | 5, 6 | 8, 9, 10, 11, 12 | visitor |
| Haemulidae | 0.24 | *Pomadasys crocro* | 0.24 | 1, 2 | 11, 12 | transient |
| Lutjanidae | 0.64 | *Lutjanus apodus* | 0.24 | 7 | 5 | transient |
| Lutjanidae | | *Lutjanus griseus* | 0.08 | 7 | 5 | transient |
| Lutjanidae | | *Lutjanus jocu* | 0.32 | 5, 6, 8 | 5, 8, 9, 10 | visitor |
| Megalopidae | 0.48 | *Megalops atlanticus* | 0.48 | 2, 4 | 7, 11 | transient |
| Mugilidae | 9.32 | *Agnostomus monticola* | 1.19 | 1, 2 | 1, 6, 8, 9, 11 | visitor |
| Mugilidae | | *Mugil curema* | 7.96 | 1, 2, 3, 4, 5, 7, 8 | 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12 | resident |
| Mugilidae | | *Mugil liza* | 0.16 | 5, 6 | 7, 8 | visitor |
| Myliobatidae | 0.32 | *Aetobatus narinari* | 0.32 | 3, 5 | 4, 5 | visitor |
| Paralichthyidae | 0.16 | *Citharichthys spilopterus* | 0.16 | 3, 6 | 3, 7 | transient |
| Poeciliidae | 0.56 | *Poecilia vivipara* | 0.56 | 4, 5 | 11 | transient |
| Polynemidae | 0.64 | *Polydactylus virginicus* | 0.64 | 5, 6, 7, 8 | 4, 5, 6, 12 | visitor |
| Sciaenidae | 5.57 | *Bairdiella ronchus* | 3.03 | 1, 2, 3, 4, 5, 6, 7, 8 | 2, 3, 4, 5, 6, 7, 8, 11, 12 | resident |
| Sciaenidae | | *Cynoscion jamaicensis* | 0.72 | 5, 7 | 5, 7 | transient |
| Sciaenidae | | *Larimus breviceps* | 0.40 | 5, 7 | 5, 6 | visitor |
| Sciaenidae | | *Micropogonias furnieri* | 1.43 | 4, 5, 6, 7, 8 | 4, 5, 6, 11, 12 | visitor |
| Scombridae | 0.56 | *Scomberomorus regalis* | 0.56 | 5, 6, 8 | 2, 6, 7 | visitor |
| Sphyraenidae | 0.16 | *Sphyraena barracuda* | 0.08 | 2 | 12 | transient |
| Sphyraenidae | | *Sphyraena guachancho* | 0.08 | 7 | 5 | transient |
| Syngnathidae | 9.24 | *Microphis brachyurus* | 9.08 | 1, 2, 3, 4, 5, 6 | 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12 | resident |
| Syngnathidae | | *Pseudophallus mindii* | 0.16 | 1 | 7, 9 | transient |
| Tetraodontidae | 1.19 | *Lagocephalus laevigatus* | 0.40 | 5, 6, 8 | 2, 5 | transient |
| Tetraodontidae | | *Sphoeroides testudineus* | 0.80 | 8 | 1, 2, 3, 4, 8, 11 | visitor |
| Trichiuridae | 0.88 | *Trichiurus lepturus* | 0.88 | 6, 7 | 6, 7 | visitor |



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Table 2. Relative abundance and locations of fish captured in the Espiritu Santo estuary, Puerto Rico in June and July 2004. Stations refer to the sampling stations where fish were captured. Station numbers in italics indicate that the species was captured only during night sampling

| Family | Species | Relative abundance (day) | Relative abundance (day + night) | Stations |
|---|---|---|---|---|
| Belonidae | *Strongylura timucu* | — | 3.0 | *5*, *8* |
| Carangidae | *Caranx hippos* | — | 1.5 | *8* |
| Carangidae | *Caranx latus* | 2.3 | 6.0 | *2*, *8* |
| Carangidae | *Oligoplites saurus* | 2.3 | 4.5 | 8 |
| Carangidae | *Selene vomer* | 4.7 | 3.0 | 7, 8 |
| Centropomidae | *Centropomus ensiferus* | — | 3.0 | *5* |
| Centropomidae | *Centropomus pectinatus* | — | 9.0 | *2*, *8* |
| Centropomidae | *Centropomus undecimalis* | 2.3 | 1.5 | 4 |
| Cichlidade | *Oreochromis mossambicus* | 4.7 | 3.0 | 1, 2 |
| Clupeidae | *Opisthonema oglinum* | 9.3 | 7.5 | 3, 5, 8 |
| Eleotridae | *Eleotris pisonis* | 4.7 | 1.5 | 5 |
| Elopidae | *Elops saurus* | — | 1.5 | 8 |
| Engraulidae | *Anchovia clupeoides* | — | 1.5 | *5* |
| Engraulidae | *Cetengraulis edentulus* | — | 1.5 | *2* |
| Gerreidae | *Diapterus rhombeus* | 2.3 | 3.0 | *2*, 4 |
| Gerreidae | *Diapterus auratus* | 2.3 | 1.5 | 2 |
| Haemulidae | *Pomadasys crocro* | 2.3 | 3.0 | 2 |
| Lutjanidae | *Lutjanus jocu* | 7.0 | 4.5 | 5, 7 |
| Mugilidae | *Mugil curema* | 11.7 | 4.5 | 1, 3, *8* |
| Polynemidae | *Polydactylus virginicus* | 4.7 | 9.0 | *2*, *5*, *7*, *8* |
| Sciaenidae | *Bairdiella ronchus* | 4.7 | 11.9 | *2*, *5*, *6*, *8* |
| Sciaenidae | *Cynoscion jamaicensis* | — | 1.5 | *8* |
| Scombridae | *Scomberomorus regalis* | 7.0 | 4.5 | 5, *8* |
| Sphyraenidae | *Sphyraena barracuda* | 2.3 | 1.5 | 5 |
| Sparidae | *Archosargus rhomboidalis* | 4.7 | 1.5 | 8 |
| Syngnathidae | *Microphis brachyurus* | 18.6 | 4.5 | 4, 5 |
| Tetraodontidae | *Sphoeroides testudineus* | 2.3 | 1.5 | 8 |

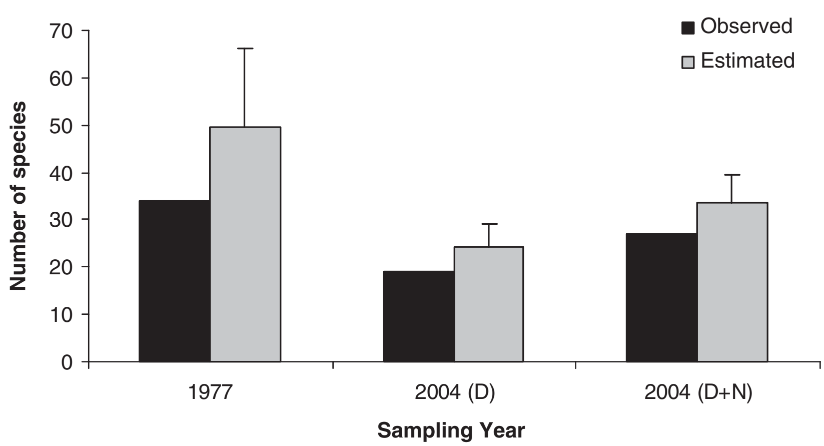


Figure 2. Fish species richness of the Espiritu Santo estuary in 1977 and 2004. 'Observed' refers to the observed number of species and 'Estimated' refers to the estimated species richness (calculated with the Chao1 species richness estimator). 2004 (D) indicates the number of species captured during day sampling only while 2004 (D + N) indicates the number of species found during day and night sampling combined. Night sampling was not conducted in 1977.

freshwater-oriented. These changes coincided with apparent increases in estuarine salinity. The mean, minimum, and maximum bottom salinity was higher in 2004 than in 1977 at all sampling stations (Figure 5(c), (d)). Surface salinity was similar in 2004 and 1977 (Figure 5(a), (b)); however, rainfall in the region was much higher in 2004 than 1977 (Figure 5(e), (f)).



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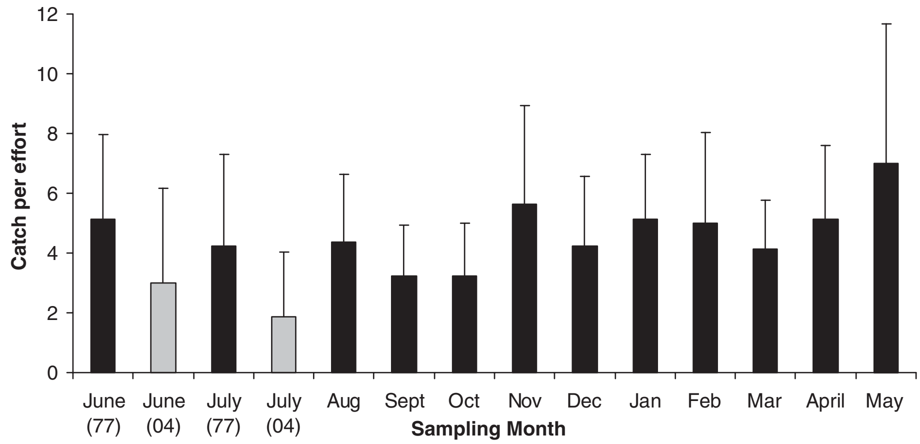


Figure 3. Catch per effort in the Espiritu Santo estuary by month in 1977 compared with June and July 2004.

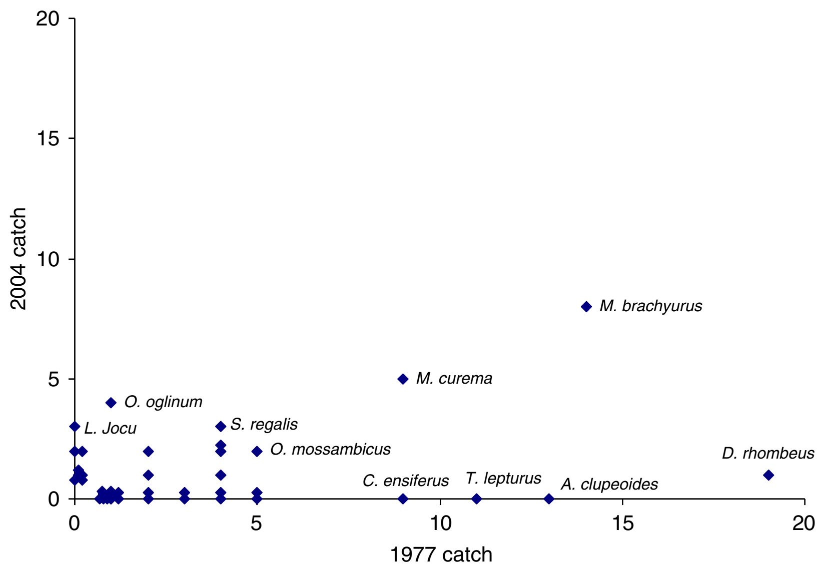


Figure 4. Number of fish by species collected in the Espiritu Santo estuary in 1977 versus 2004. Names of more common species are presented.

Because 1977 data were available only in summary form, it was not possible to apply statistical tests to these comparisons.

Habitat classifications were not available for many species and, when available, they were often vague. Although these limitations prevented formal analysis, all four species noted to prefer estuarine creeks and tributaries (*Pseudophallus mindii*, *Agonostomus monticola*, *Dormitator maculates* and *Bathygobius soporator*) were not redetected in 2004. The percentage of species classified as low, medium, and high resilience was similar in 1977 and 2004.

## DISCUSSION

### Interpretation of long-term change from limited data

Often, only limited historical data are available for studies of long-term change (Drayton and Primack, 1996). Several methods have been used to improve the strength of conclusions drawn from historical data. For example, using the same collector or training researchers in identical methods serves to minimize sampling biases between surveys (Anderson



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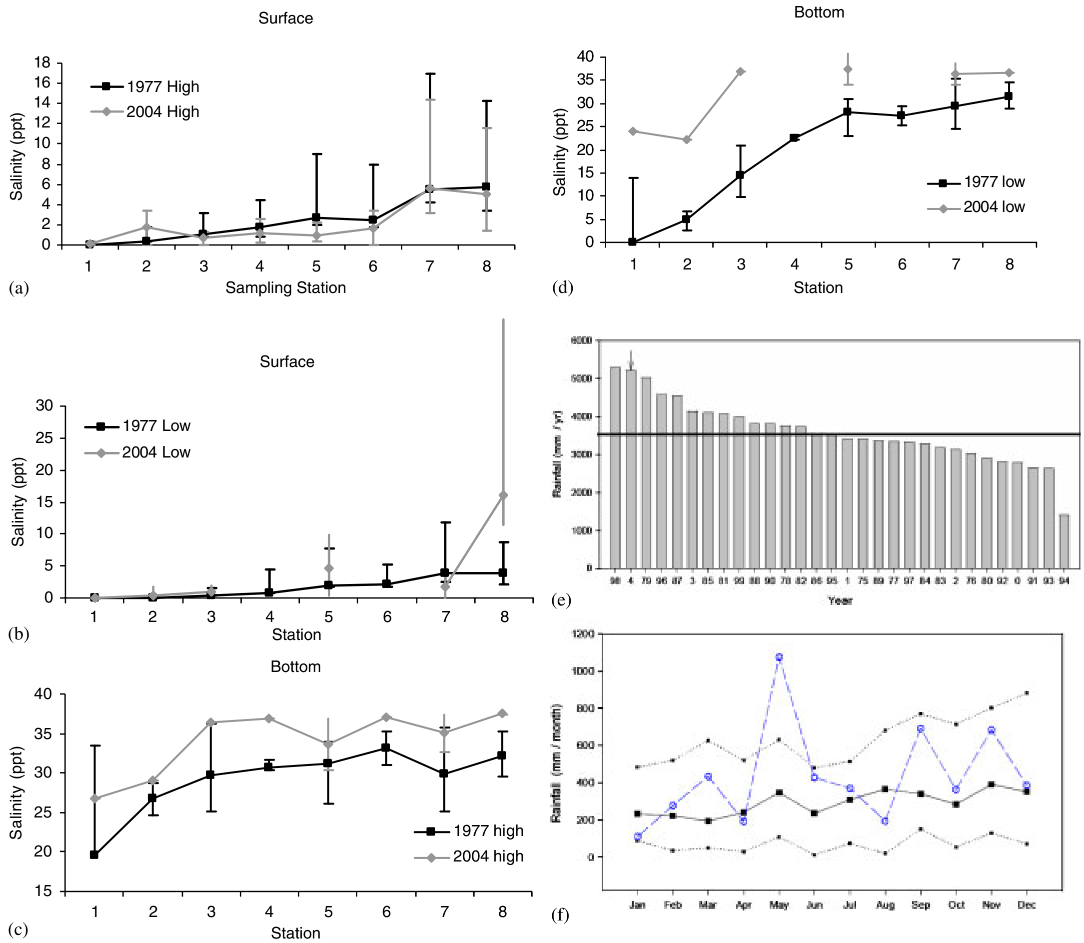


Figure 5. Average surface (a,b) and bottom (c,d) salinity (ppt) at high (a,c) and low (b,d) tide in the Espiritu Santo estuary in 1977 and 2004. Error bars represent minimum and maximum salinity (standard errors for 1977 salinity data could not be calculated because only summaries of these data are available). Annual rainfall (1975 to 2004) from wettest to driest year for the Luquillo Experimental Forest is shown in Figure 5(e). Figure 5(f) shows monthly average, minimum, and maximum rainfall for 1975–2003 in comparison with 2004. Monthly values for 2004 are shown as open circles. Figure 5(e) and (f) are adapted from Ramírez *et al.* (2005).

*et al.*, 1995). Standardizing sampling effort and gears or otherwise accounting for sampling effort will strengthen the ability to draw conclusions about long-term change (Patton *et al.*, 1998). Consideration of change at multiple spatial scales (Anderson *et al.*, 1995; Patton *et al.*, 1998) and over multiple years (Cabral *et al.*, 2001) may further improve ability to draw statistical conclusions.

Although the aforementioned methods cannot always be applied owing to the nature of historical data collections and records, these data may still reveal important signals of change. For example, Drayton and Primack (1996) identified changes in the plant community of a Boston woodland between 1894 and 1993, despite loss of some historical data and methodological questions about the original study. Reinthal and Stiassny (1991), compared compilations of historical museum records with a six-week preliminary survey conducted in 1989. Even with this limited dataset, they reported dramatic reductions in freshwater fish in Madagascar, which coincided with an increase in exotic species. Several factors increase the robustness of the conclusions drawn from comparisons of current and historical data in this study: (1) the primary investigator of the 1977 survey ensured consistency in sampling methods between the 1977 and 2004 surveys; (2) sampling effort was standardized between surveys; and (3) identical gear was used in both surveys.

## Differences in the Espiritu Santo fish community between 1977 and 2004

This study strongly suggests declines in fish species richness (Figure 2) and possibly abundance (Figures 3 and 4) in the Espiritu Santo estuary. However, studies from other regions suggest that estuarine fish may be relatively resilient to environmental change. For example, in a comparison of fish communities over a 21-year period, Richardson *et al.* (2000) found that fish communities in the industrialized estuary of the Fraser River showed no more change than those in the more protected freshwater reaches of the river. Reinthal and Stiassny (1991) reported losses of many freshwater fish species in Madagascar but found little evidence of decline in euryhaline species. Despite large changes in vegetation over a 4-year period, Whitfield (1986) found little change in the fish community of a South African estuarine lake. Meng *et al.* (1994), however, reported declines of native estuarine species in the San Francisco bay estuary coinciding with increases in exotic species and declines in freshwater inflow during a 14-year study.

In contrast to other studies of tropical freshwater fish communities (e.g. Reinthal and Stiassny, 1991; Kaufman, 1992), declines in species richness in the Espiritu Santo did not coincide with increases in exotic species. Only one exotic species, *O. mossambicus,* was collected from the estuary, and its numbers declined between 1977 and 2004. Exotic species may be relatively uncommon in this estuary because it is distant from major ports. In addition, improvements in water quality of the estuary over the past 27 years may have prevented *O. mossambicus*, which tolerates turbid, nutrient-rich waters, from out-competing native species.

Given the lack of research and monitoring of Caribbean island estuarine fish, little is known about species that may have been extirpated or are in danger of being extirpated from the Espiritu Santo or other estuaries. In a report of extirpated species in the Caribbean Isles, insufficient data were available to estimate the number of extirpated fishes (Johnson, 1988). Only one species found in the Espiritu Santo estuary in 1977, *Mugil liza*, is considered to be a species 'at risk' in Puerto Rico. Only one specimen of *M. liza* was found in 1977 and none were found in 2004. Given the rarity of this species in 1977, more sampling is needed to determine if this species has been extirpated from the Espiritu Santo estuary. Additional study and monitoring of estuaries and estuarine fishes is needed to determine if other fish are at risk.

## Influence of environmental change

### *Salinity and freshwater diversion*

Freshwater inflow to the Espiritu Santo estuary has decreased due to upstream water diversions (Crook *et al.*, 2007). While the exact change in inflow since 1977 is unknown, the largest water intake on the Espiritu Santo river, constructed in 1984, is estimated to extract approximately 34% of the instream flow on average and as much as 100% of the flow during low flow periods (Benstead *et al.*, 1999). These upstream changes, combined with changes to the marine and estuarine environment (i.e. dredging and coral removal at the mouth of the estuary) which may increase the marine influence and penetration of the salt wedge into the estuary are reflected in an increase in bottom salinity at all stations of the Espiritu Santo estuary in 2004 (Figure 5). This increase occurred despite the fact that 1977 experienced average rainfall while 2004 was a relatively wet year, with May 2004 experiencing record high rainfall for 1975–2004 (Ramírez *et al.*, 2005).

Changes in freshwater inflow and salinity structure have been shown to regulate fish communities in many estuaries (Meng *et al.*, 1994; Freyrer and Healey, 2003; Barletta *et al.*, 2005). Results from the present study suggest that altered inflow and estuarine salinity has affected the Espiritu Santo fish community. In addition to declines in species richness and catch per effort, in 2004 fewer freshwater tolerant species (25%) than marine oriented species (53%) were redetected. This finding suggests that freshwater-oriented species are either more vulnerable to environmental change than marine or euryhaline species or that long-term change in freshwater inflow and estuarine salinity are decreasing adequate habitat for these species. Given these findings, and the ever increasing demand for freshwater in Puerto Rico (Ortiz-Zayas and Scatena, 2004), studies of freshwater requirements for Puerto Rico's estuaries are urgently needed.

### *Urbanization*

Increases in urbanization surrounding rivers and estuaries in Puerto Rico's coastal plains may have also contributed to declining species richness in the Espiritu Santo estuary. While a small mangrove fringe remains around the estuary, most of the mangroves surrounding creeks, backwaters, and tributaries to the Espiritu Santo estuary have been removed as these areas were developed for tourism and suburban development. None of the species known to inhabit estuarine creeks and tributaries (*P. mindii*, *A. monticola*, *D. maculates* and *B. soporator*) were redetected in 2004. These species, however, were detected in riverine areas above the estuary during exploratory sampling (K. Smith, personal observation), indicating that while less common in the estuary, they have not been extirpated from the Espiritu Santo river. Urbanization is a large and increasing threat to Puerto Rico's coastal plains (Thomlinson *et al*., 1996; Thomlinson and Rivera, 2000; Ramos Gonzalez, 2001) and its effects on estuarine fish communities requires future study.

### Need for long-term monitoring

Comparing historical and current data may provide valuable information on ecological trends and species declines; however, long-term monitoring is critical for detection of changes outside the range of natural variability. Temporal patterns of variability are well-documented in many temperate estuaries with established monitoring programmes. These data allow changes outside the normal range of variability to be detected. However, even with such monitoring programmes, it may only be possible to detect dramatic signals of change. For example, in an intensive multi-year study of temporal variability of physical and biotic characteristics of the Apalachicola estuary, Livingston (1987) found that fish community parameters demonstrated large, weekly variation that could mask interannual trends. No similar long-term datasets are available for Caribbean island estuarine fish communities and therefore differences in the 1977 and 2004 Espiritu Santo estuarine fish community could not be examined within the context of natural population fluctuations. Future studies are clearly needed to monitor and determine patterns of variability in the Espiritu Santo estuary.

This study illustrates the need to ensure that historical data are appropriately archived and made available to the scientific community. In the 1970s, the Center for Energy and Environmental Research (CEER, 1979) funded several studies of the environment (sediment and water quality) and biota (plankton, crustacean, molluscs, and fish) of the Espiritu Santo estuary. As a result, more was known about the ecology of the Espiritu Santo, one of the few well described Caribbean island estuaries, in the late 1970s than at the present. The majority of this information, including the raw data for this study, was lost with the closure of the CEER. The loss of these data precludes most statistical analyses as well as an examination of change in fish size structure and biomass in the Espiritu Santo estuary. This example illustrates the importance of preserving both short- and long-term data and the need for programmes such as the National Science Foundation's Long Term Ecological Research (LTER) programme to archive data and make it available to future generations.

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