

**STRUCTURE OF THE FISH COMMUNITY OF
JAMAICA BAY IN SPACE AND TIME**

by

Olivia Pineiro Ramirez

Submitted in partial fulfillment of the requirements for the degree
of Master of Art in Biology in the Graduate Division of Queens
College of The City University of New York

May 2018

Approved by: _____
(Sponsor)

Date: _____

TABLE OF CONTENTS

ACKNOWLEDGEMENTS	ii
ABSTRACT	1
INTRODUCTION	2
Human Impacts on Jamaica Bay	2
Environmental Improvements in Jamaica Bay	4
The Fish Community of Jamaica Bay	5
Objectives	7
MATERIALS AND METHODS	7
Description of the Samplings and Dataset	7
Statistical Analysis	9
1. Temporal Trends in Species-Specific Abundance	9
2. Spatial Pattern of Abundance, Richness and Diversity of the Fish Community.....	10
3. Temporal Changes in the Fish Community Composition.....	11
RESULTS	14
1. Temporal Trends in Species-Specific Abundance	15
2. Spatial Pattern of Abundance, Richness and Diversity of the Fish Community	22
3. Temporal Changes in the Fish Community Composition.....	25
DISCUSSION	30
Temporal Trends in Species-Specific Abundance.....	30
Spatial and Temporal Changes in the Fish Community Composition	33
Future Directions	37
CONCLUSIONS	37
REFERENCES	38
SUPPLEMENTARY INFORMATION	42

ACKNOWLEDGEMENTS

It would not have been possible to write this Masters' Thesis without the help of Jesse Hornstein from the Division of Marine Resources of the New York City Department of Environmental Conservation who gave us access to this voluminous dataset. Additionally, I would like to acknowledge the financial support from the Institute of Resilience of Jamaica Bay which allows this project to become a reality.

I owe my deepest gratitude to my advisors Dr. José D. Anadón and Dr. John Waldman at Queens College, City University of New York. It has been a privilege to prepare this document under their guidance. José was the first who believed in me even when I did not. He gave me the opportunity to join his lab and introduced me to the amazing world of coding. John, with his extraordinary enthusiasm about marine life, showed me that it is possible for someone to remember the names and life cycle of more than 100 species of fishes. Their advice, encouragement and passion for ecological studies have shaped my growth as a scientist.

My special thanks to Dr. David Lathi, professor at Queens College, who taught me how to approach the scientific literature during his Evolution class. David has also provided me with unfailing support and continuous encouragement throughout these years of study.

The completion of this project could not have been accomplished without the support of my colleagues in the Anadón Lab and in the Department of Biology at Queens College. I am indebted to them for providing me with insights and helpful suggestions about my research project.

Finally, I cannot express enough thanks to my boyfriend Antonio Cádiz for the countless times he helped and supported me during this journey, both by keeping me harmonious and helping me putting pieces together.

To all of those who have been with me from the beginning to the end and to all of those who joined me later, thank you.

Olivia Pineiro.

ABSTRACT

Jamaica Bay is one of the largest coastal wetland ecosystems in New York State, one of the best bird-watching locations in the western hemisphere and an important site for recreational fishing. Unfortunately, its valuable resources are being lost. Human impacts began 150 years ago, being the late 19th to the early 20th Century a crucial time of transformations for the bay. Since 2005, huge efforts have been made to improve its natural resources. Fishes, which are integral components of Jamaica Bay's ecosystems, have received scant attention. Since they are top-level elements of the bay's food web, it is critical to gain a better understanding of their status. The goal of this thesis is to study the temporal and spatial trends of the fish community of the bay from 1987 to 2015. We used the data collected by NYDEC from nine stations in Jamaica Bay to conduct three groups of statistical analysis: temporal trends in species-specific abundance; spatial patterns of abundance, richness and diversity of the fish community; and temporal changes in community composition. Significant trends were observed for 22% of 79 species, but we did not detect any temporal significant trend for the total abundance of all species in the bay. This suggests that fish populations might be limited by the carrying capacity of the ecosystems. Our results also suggest that the characteristics of fishes (migratory or resident and pelagic or benthic) do not determine their temporal trends. In addition, the temporal differences in community composition might be explained as a result of some species being replaced by others and not because each community represents a subset of another. A multidimensional scaling analysis for the total data of the bay and for each station does not show a shift in direction during the 29-year-period which indicates that the community remained very similar to each other at both temporal and spatial scales. Taken together, our results suggest that the deterioration of the fish community could have occurred before the period analyzed in this thesis and that more time should be required to trigger a positive change in the bay's community. Nevertheless, the lack of both spatial and temporal shifts could be explained by two other plausible alternative scenarios: the community could be resilient to the environmental changes occurred in the last years, or the internal dynamics at Jamaica Bay could be masked by its surrounding communities. We propose to carry out a broader characterization of the biota of Jamaica Bay by including invertebrate groups and to explore environmental data as potential drivers for community fluctuations.

Key words: Jamaica Bay, fish community, temporal and spatial shifts.

INTRODUCTION

Jamaica Bay is one of the largest coastal wetland ecosystems in New York State and one of the most densely urbanized areas in the United States (NYCDEP, 2007). It is an important and complex network of open water, salt marsh, grassland, coastal woodland, maritime shrublands, brackfish and freshwater wetlands (NYCDEP, 2007; NYCDEP, 2014). With its geographic siting at the margin of New York Harbor, Jamaica Bay has physical and chemical characteristics in between that of the Hudson estuary and the barrier-beach bays of Long Island's south shore. The bay lies at approximately 40.6178°N, 73.8425°W (Swanson et al., 2016), in the boroughs of Queens and Brooklyn with a small portion in Nassau County (Solecki et al., 2016).

Jamaica Bay serves as a critical wildlife refuge and it is home to over two and a half million of New Yorkers (Solecki et al., 2016). The natural habitats of the bay support more than one hundred species of fishes (Trust for Public Land and NYC Audubon, 1987), 325 of bird species and many species of reptiles, amphibians and mammals (NYC, 2007; NYC, 2014). The bay is also one of the best bird-watching locations in the western hemisphere and an important site for recreational fishing (NYCDEP, 2016).

Human Impacts on Jamaica Bay

Unfortunately, the valuable resources that comprise Jamaica Bay are being lost (NYCDEP, 2016). Prior to the Euro-American settlement, it is estimated that there were about 16,000 acres of salt marsh in the bay (USFWS, 1997). As of 1971, only about 4,000 acres of salt marsh remained (National Academy of Sciences and

National Board of Engineering 1971). Over the last 150 years, interior wetland islands have been removed as a result of extensive filling operations; shorelines have been hardened to stabilize and protect human communities; deep channels have been dredged, altering bottom contours and affecting natural flows; and natural tributaries have disappeared (NYCDEP, 2007; NYCDEP, 2014; NYCDEP, 2016).

However, the late 19th to the early 20th Century represented a crucial time of transformations in the bay. Jamaica Bay experienced profound degradation because of the New York City's expansion, serving as a waste depository and siting of massive infrastructure features. The large-scale business community saw the bay as a wasteland onto which their plants could be laid. Additionally, high levels of sport fishing and shell fishing activity were recorded for this period. Nevertheless, the most profound alteration of the bay occurred with the development of the railway at the first half of the 20th Century (NYCDEP, 2007; NYCDEP, 2014; NYCDEP, 2016).

Immense waste sites, sewage treatment facilities, highways and two major airports (Waldman and Solecki, 2018) impacted Jamaica Bay. The John F. Kennedy

International Airport and the Floyd Bennett airfield were developed by filling in a large portion of the bay with dredged material from other portions of the bay.

Dredging and removal of sand from the bottom of the bay have increased the average depth from 3 to 16 feet (NYCDEP, 1994). Gordon and Houghton (2004) cited that this lack of sediments could have been a contributor to salt marsh disappearance. The estuarine system as a whole has also been altered to the point where freshwater input is derived almost exclusively from sewer overflows, wastewater pollution control plants and storm sewers (NYCDEP, 2007). These

activities have synergistically influenced historic flow patterns in the bay, eradicated natural habitats, impacted water quality, and modified the rich ecosystem that was present prior to the extensive urban development of the watershed (NYCDEP, 2007; NYCDEP, 2014; NYCDEP, 2016).

Environmental Improvements in Jamaica Bay

In 2005, it was established the Jamaica Bay Watershed Protection Plan (JBWPP). Since the inception of this plan, huge efforts have been made to improve the health of the bay. Overall, New York Harbor's water quality is the cleanest it has been in nearly 100 years (NYCDEP, 2016). The 240 million gallons of daily wastewater handled by the four waste water treatment plants on Jamaica Bay resulted in the discharge of more than 50,000 pounds of nitrogen each day. Current nitrogen discharges into Jamaica Bay have been reduced to around 26,000 pounds per day since the mid-1990s. Artificial structures have been built in the bay to encourage the growth of ribbed mussels. In January 2010, the NYCDEP initiated a contract to restore 46 acres of wetlands and coastal grassland adjacent to Paerdegat Basin that is one of the tributaries of Jamaica Bay. The Science and Resilience Institute at Jamaica Bay was established in 2013 to gather information about the matters concerning the bay. Moreover, green infrastructure practices are being designed and constructed in the bay to manage storm water runoff from surfaces such as streets, sidewalks and rooftops (NYCDEP, 2016). In August 2015, a marsh floating island was constructed in the bay as a wave attenuator acting as a proxy for oyster reefs. Additionally, another project, which includes the construction of five artificial oyster bed structures, has started in September 2016 (NYCDEP, 2016).

The Fish Community of Jamaica Bay

Fishes are integral components of Jamaica Bay's ecosystems and yet to date they have received scant attention. In spite of the conservation actions in Jamaica Bay during the last decades, and mainly after the Hurricane Sandy in 2012 that represented another strong stressor to the bay, most studies that include fish in the bay focus on the environmental impacts of contamination (Waldman, 2008) and not on the fundamental biology of its fishes. The ichthyofauna of the Hudson River watershed and the broader marine waters of New York has been characterized (Briggs and Waldman, 2002; Waldman et al., 2006), but the problems to understand the Jamaica Bay fish community relies on that many species have broadly distributed and highly mobile marine populations that move in and out of the bay seasonally (Handel et al., 2016). In general, the ecological knowledge of Jamaica Bay is scarce, based mainly on observations, with few species or interactions studied in depth or over long time and lacks a holistic understanding of the dynamics of the system (Swanson et al., 2016).

Marine fish species of the New York region have shown substantial changes over time (Waldman, 2006). Species such as sheepshead and black drum, common in the 1800s, were rarely seen in recent decades. Striped bass numbers reflect spawning success in the nearby Hudson and the distant Chesapeake Bay. Winter flounder numbers have crashed, possibly due to warming waters. The panmictic American eel are fewer in number due to overfishing throughout its range, which then diminishes new recruits, including to Jamaica Bay. These are just a few examples of the fact that each fish species has its own trajectory as it integrates the many

ecological factors that regulate abundances and that one result of these individual trajectories is shifting fish communities.

Since 1988, the New York City Department of Environmental Conservation (NYCDEC) has been surveying the bay, gathering the most comprehensive information that exists about its fish community (Handel et al., 2016). Nevertheless, the database resulted from this long-term monitoring effort has remained untapped, limiting the ability to understand the spatial and temporal patterns of species, which is critical to target management actions (Handel et al., 2016). As fishes are top-level elements of the bay's food web and because they were the basis of important recreational and commercial activities, it is critical to gain a better understanding of the fish community of Jamaica Bay.

Taking into account that fish communities could also vary in space, even at subregional levels (Oviatt and Nixon, 1973), it would be expected to find spatial heterogeneity in fish communities in Jamaica Bay where creeks around the edge of the bay have lower salinities and weaker currents than near Rockaway Inlet. The former would be more likely to contain species such as mummichogs, sticklebacks, and white perch, whereas for the latter, spanish mackerel, false albacore, and triggerfish. Thus, given the spatial, hydrodynamic, and chemical complexity of the bay, we anticipate multiple distinct fish communities within it.

Objectives

The overarching goal of this thesis is to study the temporal and spatial trends of the fish community of Jamaica Bay during the period 1987-2015. The specific objectives of the work are to:

1. Explore temporal trends of abundance for each fish species present in Jamaica Bay.
2. Analyze and compare temporal trends of total abundance, richness and diversity among nine sampled stations.
3. Study temporal and spatial changes in fish community composition.

Our overall research question is whether species richness, abundance, diversity and community composition have changed through time and space. We anticipate a shift of the community along the years and among the stations, expressed in increases or decreases of abundance, richness or diversity. Additionally, we expect to find the first years of the analyzed period grouped closely and apart from the last years in the multidimensional scaling.

MATERIALS AND METHODS

Description of the Samplings and Dataset

In the present work we have made use of the fish data collected by The New York Department of Environmental Conservation (NYDEC) in the annual seine survey of young striped bass from the Hudson River (Handel et al., 2016). The survey has been conducted since 1984 and occurs in the western bays of Long Island with

considerable effort in Jamaica Bay. However, samplings during the first years (1984-1986) did not follow the same methodology of counting all observed species (i.e., they were focused only on some specific species) as during the rest of the years (Jesse Hornstein, personal communication).

Nine stations (stations 1, 2, 5, 6, 8, 10, 16, 17 and 22) have been sampled consistently in the bay over the period 1987-2015 (Figure 1). Four of these stations (Station 6, 8, 10 and 16) are located close to the exit of the inlets of water which persist as remains of the historic tributary streams. Two of the stations (station 6 and 8) are on the edges of the bay where the John F. Kennedy International Airport has been built. The station 5 is at the most northeaster portion of the Broad Channel Island. The station 17 is the closest to the exit of the bay to the Atlantic Ocean. Stations 1, 2 and 22 are on the Rockaway Peninsula.

Some samplings occurred in April and November, but the standard sampled months were from May through the end of October. Prior to the year 2000, sampling was conducted twice a month in both May and June, and once a month in July through October. From 2000 onwards, sampling was conducted bi-weekly from May-October. The standard gear used for sampling was a 200 foot x 10 foot x 1/4 inch square mesh beach seine, with a 25 foot x 12 foot x 3/16 inch square mesh bunt area (Jesse Hornstein, personal communication). A table showing the number of samplings per year at each station is in Supplementary Information Table S1.

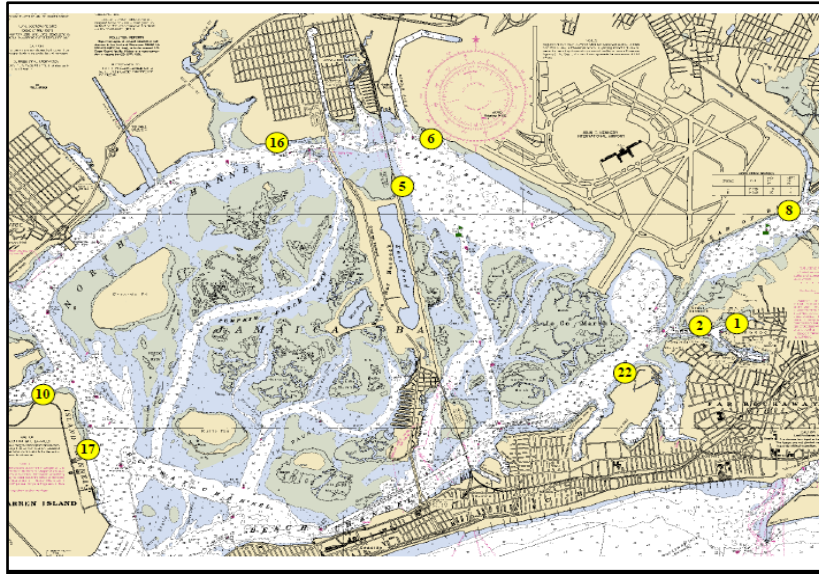


Figure 1. Map of Jamaica Bay with the nine stations (Stations 1, 2, 5, 6, 8, 10, 16, 17 and 22) still being sampled in the bay and consistently sampled from 1987 to 2015.

Statistical Analysis

1. Temporal Trends in Species-Specific Abundance

Temporal trends of abundance for each species were obtained as the sum of the total values of abundances for each station in one year for each species. This calculation rendered one single value of abundance (from all stations' abundances) for each year for each species. These values of abundance per species were previously standardized by sampling effort in each year as follows: the total value of abundance per year for each species was divided by the number of samplings in each year. After calculating the natural logarithmic of the values of abundance, we tested the existence of temporal trends by means of a linear regression.

Fishes were classified in four ecological categories: Migratory-Benthic, Migratory-Pelagic, Resident-Benthic and Resident-Pelagic (Supplementary Information Table S2). Migratory and resident categories refer to the use of the estuary. Species which

live their entire life in the bay, estuarine obligate, were classified as resident and those that are estuarine opportunistic as migratory. Additionally, those fishes which live on the bottom of the bay were classified as benthic and the rest which live in the water column as pelagic. By means of linear regression, we explored the temporal trends of abundance for the total migratory, resident, benthic, pelagic and total of species. Furthermore, in order to test whether species ecological categories influence temporal trends in abundance, we carried out generalized linear model analyses. In these models, we considered two different binary response variables: significant-positive trend / not significant positive trend, and significant-negative trend / not significant-negative trend. The explanatory variables were the use of the bay by fishes (Migratory or Resident) and their position in the water (Benthic or Pelagic).

2. Spatial Pattern of Abundance, Richness and Diversity of the Fish Community

We tested the existence of temporal trends of total abundance, total richness and diversity at each station by means of a linear regression. Annual total abundance per stations was considered as the sum of the total values of abundances of all species in one year for each station. This calculation rendered one single value of abundance (from all species' abundances) for each year at each station. Annual total richness per stations was referred to the number of species in each year at each station. The Shannon index that characterizes the community structure and accounts for both abundance and evenness of species was used as a measure of diversity. Values of abundance and richness per stations were standardized by sampling effort in each year as follows: the total value of abundance and richness per year for each station

were divided by the number of samplings in each year. These values of abundance suffered also a natural logarithmic transformation.

3. Temporal Changes in the Fish Community Composition

Changes in the fish community composition were measured by means of beta diversity and multidimensional scaling. Beta diversity was used to explore the causes of the temporal fluctuations in the community composition considering simultaneously all years and stations. In addition, the multidimensional scaling was conducted to detect any temporal disturbance in Jamaica Bay within a particular period of years, indicated by separation or aggrupation of years in a graph.

In a first step, we calculated and represented in a density plot the individual contribution of the components of beta diversity to the overall beta-diversity of the fish community in Jamaica Bay. Beta diversity is the variation in species composition among sites and can be divided in two components or patterns: nestedness and turnover. The nestedness component describes differences in community composition due to differences in species richness. Nestedness occurs when the biotas of sites with smaller number of species are subsets of the biotas at richer sites, reflecting a process of species loss. On the other hand, turnover implies the replacement of some species by others (Baselga, 2012). We used the library *betapart* (Baselga et al., 2018) to partition beta diversity into its components by means of Sørensen dissimilarity (β_{SOR}) index. This index is one of the most used measures of beta diversity due to its dependence on the proportion of species shared between

two community (Baselga, 2010) and needs a presence (represented as 1) and absence (represented as 0) matrix as input.

Taking into account the irregularities in sampling effort (Figure 2) and the strong positive correlation ($r=0.79$, $p=2.96e-06$) between total richness in each year and number of samplings per years in Jamaica Bay, we assumed that nestedness (species loss among sampling points) could be strongly determined by this unequal number of samplings. Thus, the contribution of nestedness to the overall beta diversity could be explained by the irregular sampling.

In a second step, the characterization and comparison of the fish community across time was done by means of a non-parametric multivariate approach, multidimensional scaling (MDS; Legendre and Legendre, 2012) using the library *vegan* (Oksanen, 2015). An MDS ordination is essentially a map of samples in which the distance between any two samples (distance between years or species in our map) is a reflection of their relative similarity. Thus, samples positioned closely to each other are very similar in community composition, and points that are further apart are less similar in their composition. The MDS was done for the total data in Jamaica Bay (adding together abundance data from all sampling sites in each year), for species classified according to their ecological categories (Migratory-Benthic, Migratory-Pelagic, Resident-Benthic and Resident-Pelagic) and per sampling stations. We assessed the temporal dissimilarities of the fish community according to the

turnover component of beta diversity (i.e. removing the effect of nestedness) which should have reduced the bias by unequal sampling effort.

MDS uses as input a dissimilarity matrix that contains dissimilarity measures for all pairwise comparisons (years or species in these analyses). As a dissimilarity measure we used the Bray-Curtis similarity index that is the most commonly used for community analyses. The Bray-Curtis index represents a better methodological approach when quantifying multiple-site dissimilarity measures (Oksanen, 2015). We obtained a Bray-Curtis dissimilarity matrix with the library *betapart* that allowed us to separate the components of abundance-based multiple-site dissimilarity caused by balanced variation in abundance and by abundance gradients in which one assemblage is a subset of another (Baselga, 2017). These components are analogous to nestedness and turnover-resultant components of incidence-based dissimilarity (Baselga, 2012).

All the analyses and plots were performed in R (R Development Core Team, 2010).

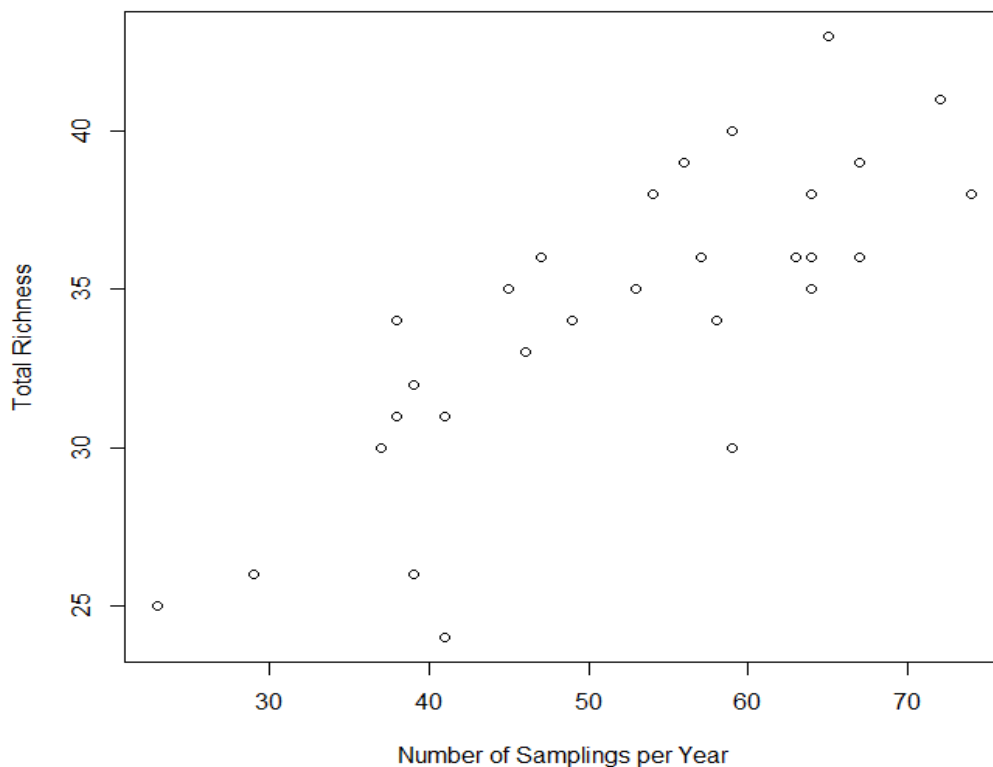


Figure 2. Scatter plot illustrating the correlation between total richness per year (adding the nine stations) and sampling effort per year. A strong positive correlation ($r=0.79$, $p=2.96e-06$) between these two variables was found.

RESULTS

The total analyzed data included 1,467,761 individuals distributed in 79 species of fishes. From these 79 species, 35 were classified as Migratory-Benthic, 28 as Migratory-Pelagic, 15 as Resident-Benthic and only one as Resident-Pelagic (Supplementary Information Table S2). There was a total of 63 migratory and 16 resident species.

1. Temporal Trends in Species-Specific Abundance

Abundance trends were analyzed individually for the 79 species of fishes from 1987 to 2015. The most abundant species were in the first place silverside and killifish (Figure 3), and in the second place, atlantic menhaden and bay anchovy (Supplementary Information Table S2). Overall, the majority of species experienced strong interannual fluctuations of abundance during the period.

In addition to these accentuated fluctuations, 17 out of 79 species had significant trends ($p < 0.05$) over the 29 years (Table 1). Four of the species (winter flounder, northern pipefish, white perch and threespine stickleback) had negative slopes indicating an abundance decline trend in the 29-year-period (Table 1 and Figure 4). These four species with a negative trend were resident. The other 13 species showed positive slopes as indicator of abundance increase trends during the period 1987-2015 (Table 1 and Figures 5A, B, C). From these 13 species, 11 (84%) were migratory. However, in this group of species with significant positive trends, species such as seaboard goby, cunner, black drum, skillettfish, and bluespotted cornetfish had low abundances and were reported mainly by the end of the sampling period (Figure 5C). These species could be classified as rare due to their low abundances and low incidences over the years. Analyzing migratory, resident, benthic, pelagic and total species in the bay, we found significant positive trends for migratory and pelagic species (Figure 6). Nevertheless, the generalized linear models to determine whether these ecological characteristics of fishes (migratory, resident, pelagic and benthic) were mediating their positive, negative or neutral trends were not significant ($p > 0.05$).

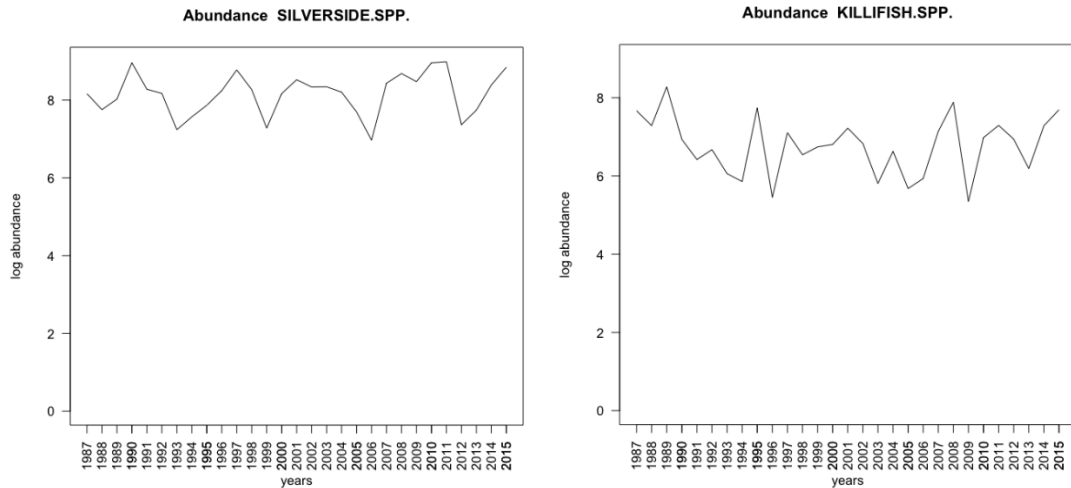


Figure 3. Temporal trend of abundance of the species silverside and killifish in the period 1987-2015. These species resulted the most abundant of the 79 studied fish species.

Table 1. Slope and p value of the significant temporal trends of abundance per fish species in the period 1987-2015 (* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$). The classification of these species accounting for their use of the bay (Migratory or Resident) and for their position in the water column (Benthic or Pelagic) is shown.

Species	slope	p	Classification
Winter flounder	-0.0504	0.0205*	Resident-Benthic
Northern pipefish	-0.0469	0.0013**	Resident-Benthic
White perch	-0.0506	0.0007***	Resident-Benthic
Threespine stickleback	-0.0093	0.0161*	Resident-Benthic
Atlantic menhaden	0.1662	0.0063**	Migratory-Pelagic
Northern kingfish	0.0848	0.0006***	Migratory-Benthic
White mullet	0.0851	0.0042**	Migratory-Pelagic
Blueback herring	0.0737	0.0173*	Migratory-Pelagic
Striped mullet	0.0552	0.0198*	Migratory-Pelagic
Blackfish tautog	0.0610	0.0024**	Migratory-Benthic
Striped anchovy	0.0555	0.0041**	Migratory-Pelagic
Striped burrfish	0.0115	0.0019**	Migratory-Benthic
Seaboard goby	0.0112	0.0487*	Resident-Benthic
Cunner	0.0068	0.0483*	Resident-Benthic
Black drum	0.0073	0.0149*	Migratory-Benthic
Skilletfish	0.0081	0.0363*	Migratory-Benthic
Bluespotted cornetfish	0.0047	0.0171*	Migratory-Benthic

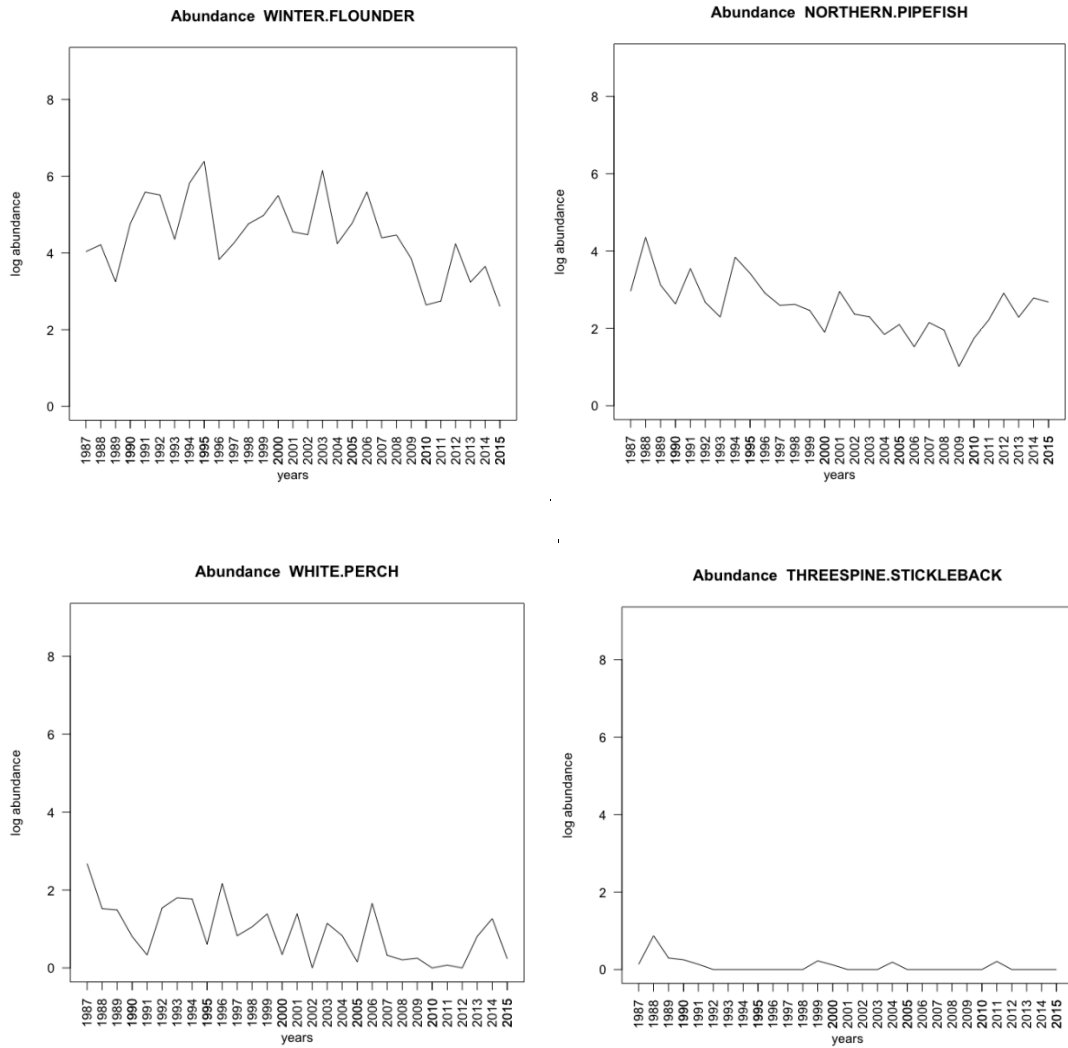


Figure 4. Temporal trend of abundance of the species winter flounder, northern pipefish, white perch and threespine stickleback in the period 1987-2015. These species showed a decrease in abundance for their populations over the analyzed period.

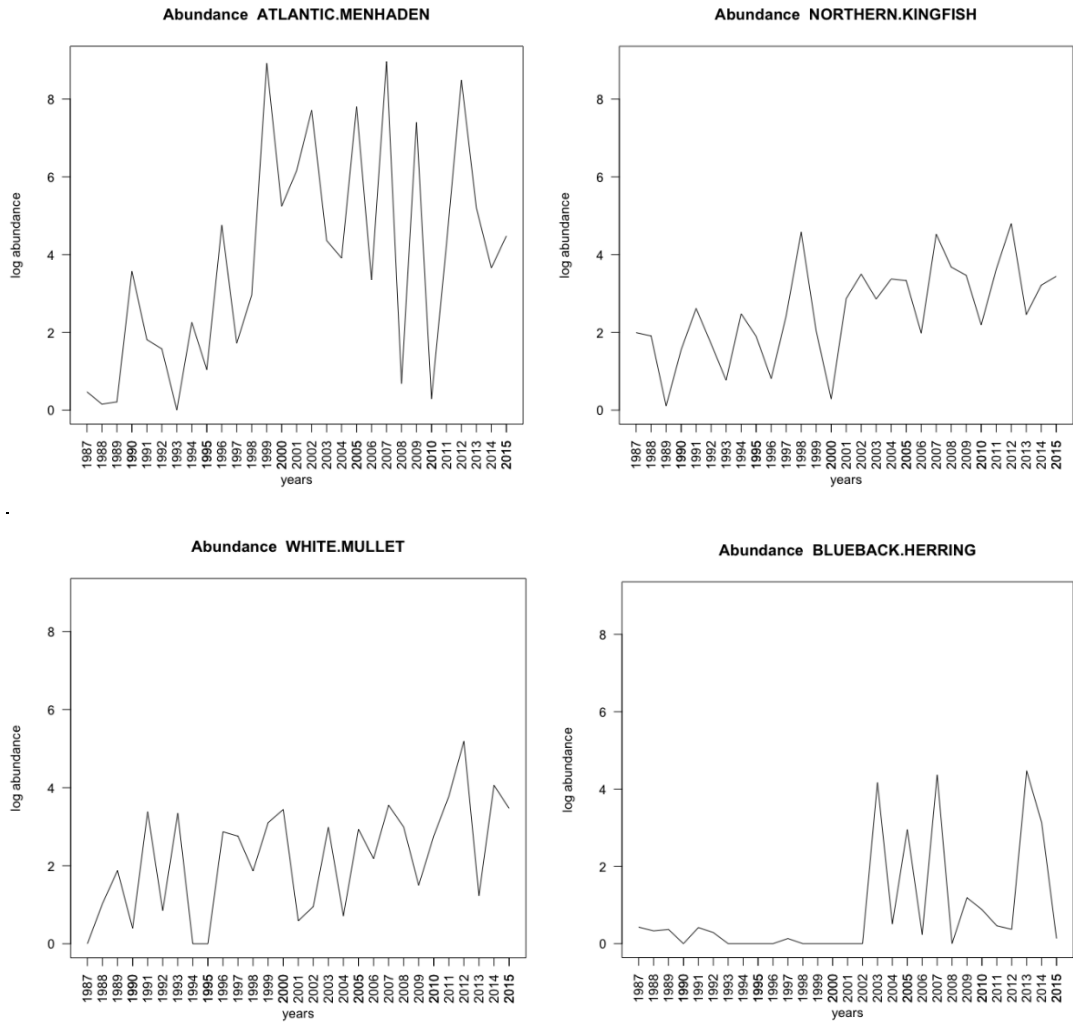


Figure 5A. Temporal trend of abundance of the species atlantic menhaden, northern kingfish, white mullet and blueback herring in the period 1987-2015. These species showed an increase in abundance for their populations over the analyzed period.

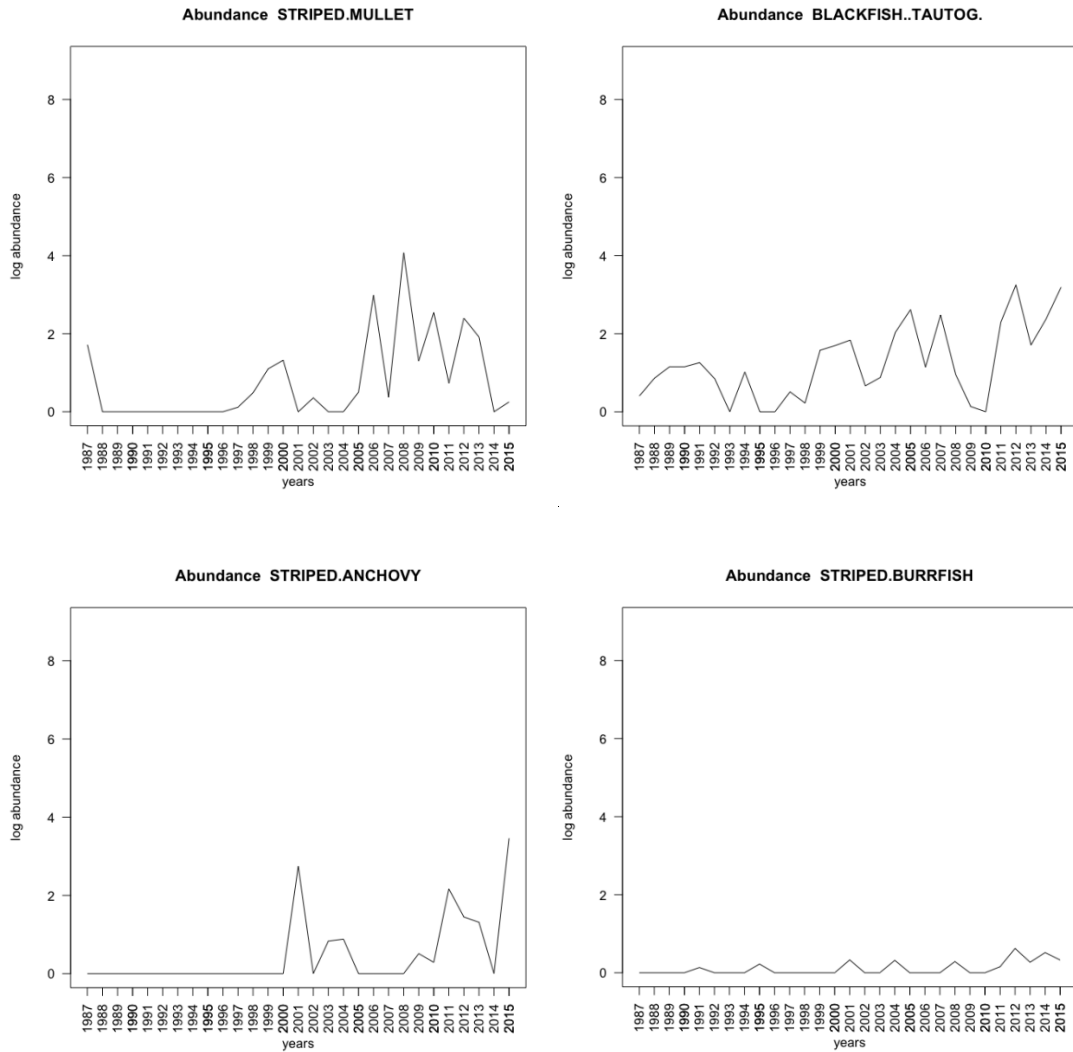


Figure 5B. Temporal trend of abundance of the species striped mullet, blackfish tautog, striped anchovy and striped burrfish in the period 1987-2015. These species showed an increase in abundance for their populations over the analyzed period.

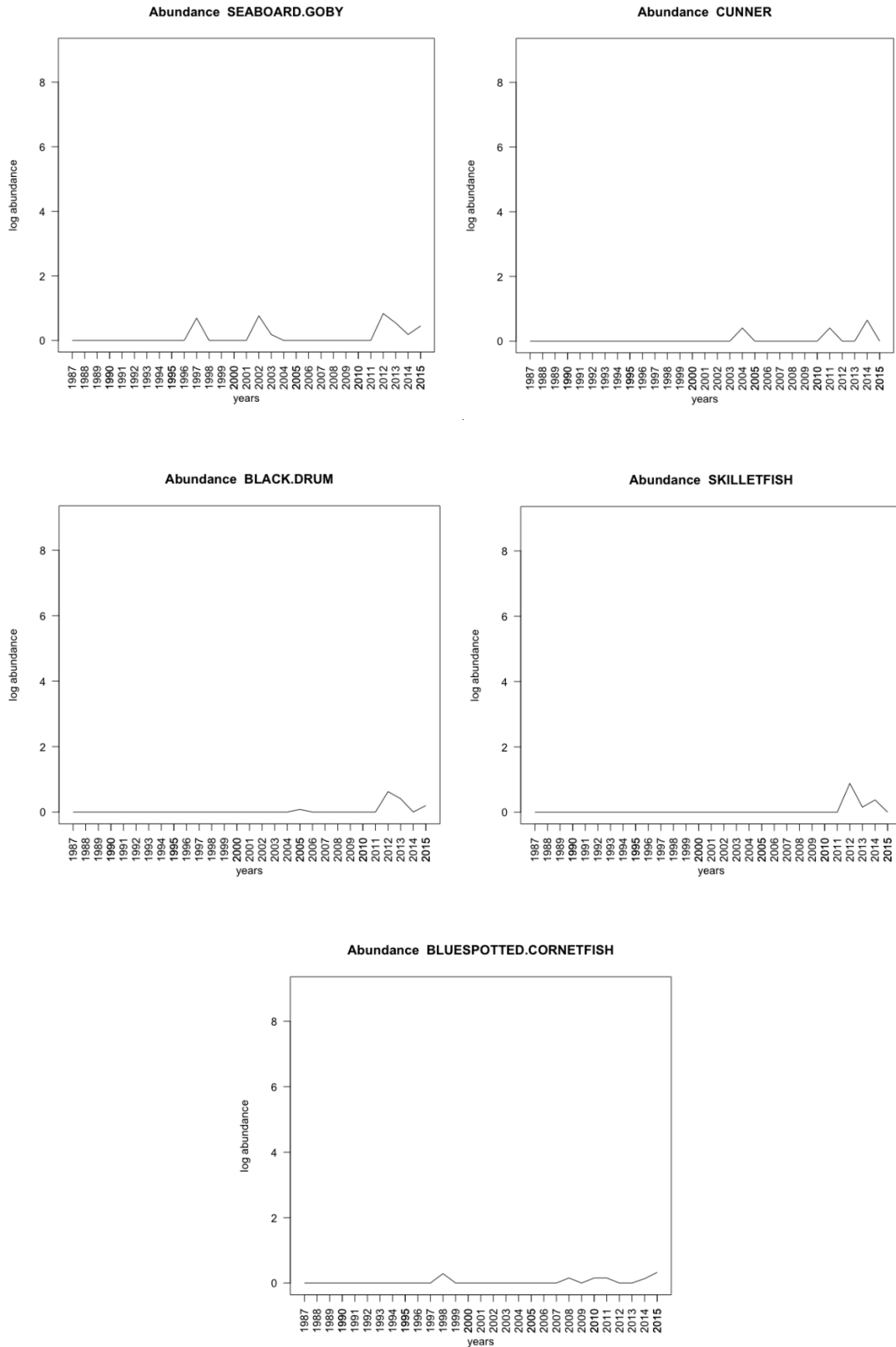


Figure 5C. Temporal trend of abundance of the species seaboard goby, cunner, black drum, skilletfish and bluespotted cornetfish in the period 1987-2015. These species showed an increase in abundance for their populations over the analyzed period.

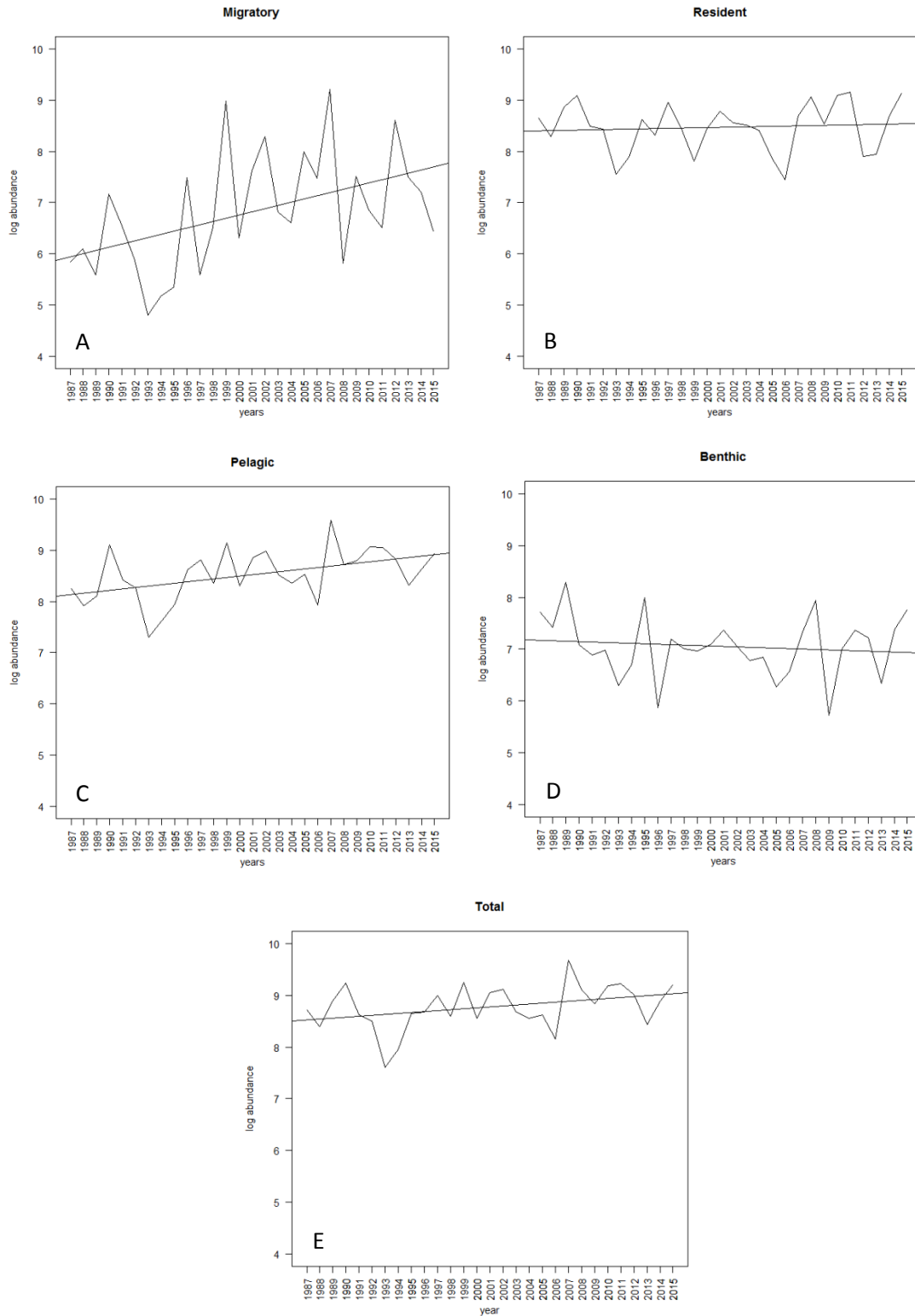


Figure 6. Temporal trend of abundance and regression lines of (A) migratory species, (B) resident species, (C) pelagic species, (D) benthic species, and (E) total species in the bay during the period 1987-2015. Migratory and pelagic species showed an increase in abundance (Migratory slope=0.06, Migratory $p=0.01$; Pelagic slope=0.03, Pelagic $p=0.01$). Resident, benthic and total abundance of species in Jamaica Bay did not show a significant trend (Resident slope=0.01, Resident $p=0.67$; Benthic slope=-0.01, Benthic $p=0.52$; Total data slope=0.02, Total data $p=0.06$).

2. Spatial Pattern of Abundance, Richness and Diversity of the Fish Community

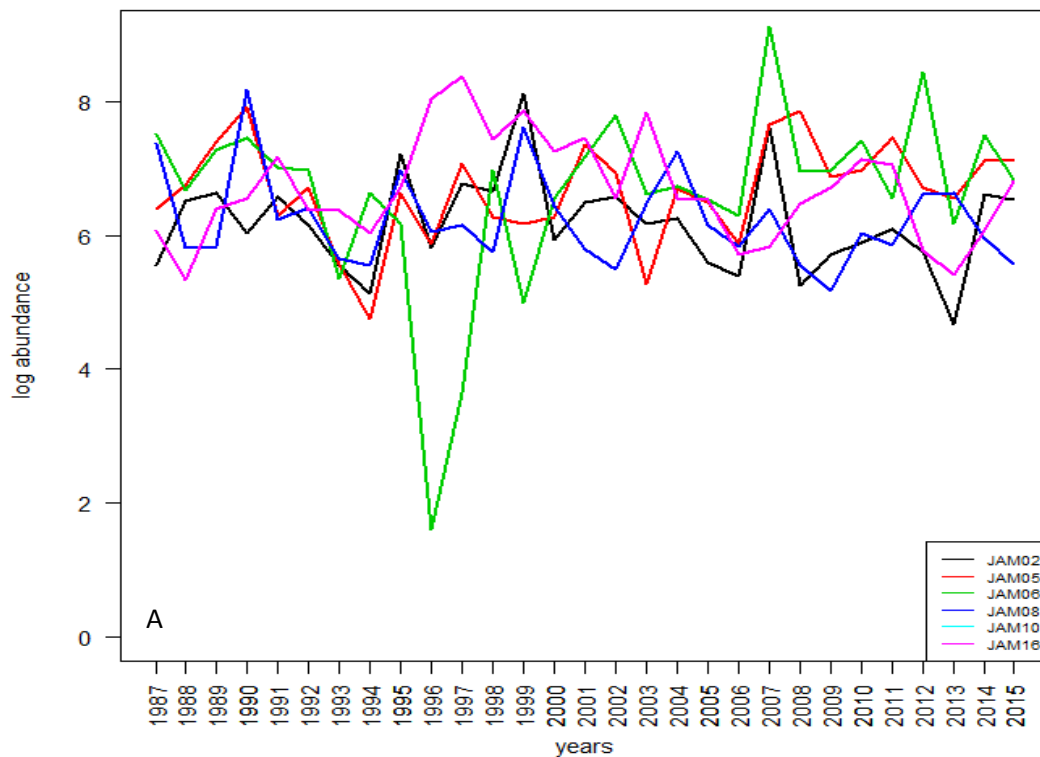
There were not significant temporal trends in total fish abundance in any of the nine stations (Table 2), but we observed common patterns of fluctuations among stations during short periods (Figure 7A). The abundance increased between years 1989-1991 to decrease simultaneously from 1992 to 1994. Five stations (2, 5, 6, 8 and 10) declined again in 1996, being this decrease very conspicuous for station six. Another peak for almost all stations was observed in 2007 with another general decline in 2013.

Regarding species richness, only one station out of nine, showed a significant negative temporal trend (Table 2). In spite of the lack of an overall trend in richness in most stations, some common trends were observed during short time interval (Figure 7B). For example, richness increased simultaneously in the years 1991, 1995, 2001, between 2004-2006 and 2012, whereas also simultaneously dropped by years 1993, 2000 and 2010. All stations experienced very similar patterns of fluctuations during the term 1987-2015. Station 16 presented the highest value of richness in 1988.

There were only two stations out of the nine, which showed significant positive trends for the diversity obtained by Shannon index (Table 2). Stations experienced similar fluctuations from 1987 to 2015. Diversity increased for the majority of the stations in years 1991, 1993-1994, 2001-2002, 2005, 2007 and 2012, whereas decreased in years 1999-2000, 2003-2004 and 2009-2010 (Figure 7C).

Table 2. Slopes and p values of the temporal trends of total abundance, total richness and diversity per sampling stations (Stations 1, 2, 5, 6, 8, 10, 16, 17 and 22) in the period 1987-2015 (* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$).

Stations	Abundance		Richness		Diversity	
	slope	p	slope	p	slope	p
JAM01	-	0,392	-	0,328	-	0,482
JAM02	-	0,453	-	0,897	-	0,216
JAM05	-	0,213	-0,048	0,0002***	-	0,371
JAM06	-	0,274	-	0,082	-	0,553
JAM08	-	0,151	-	0,337	-	0,905
JAM10	-	0,653	-	0,661	0,021	0,009**
JAM16	-	0,841	-	0,466	0,016	0,042*
JAM17	-	0,052	-	0,583	-	0,230
JAM22	-	0,630	-	0,028	-	0,450



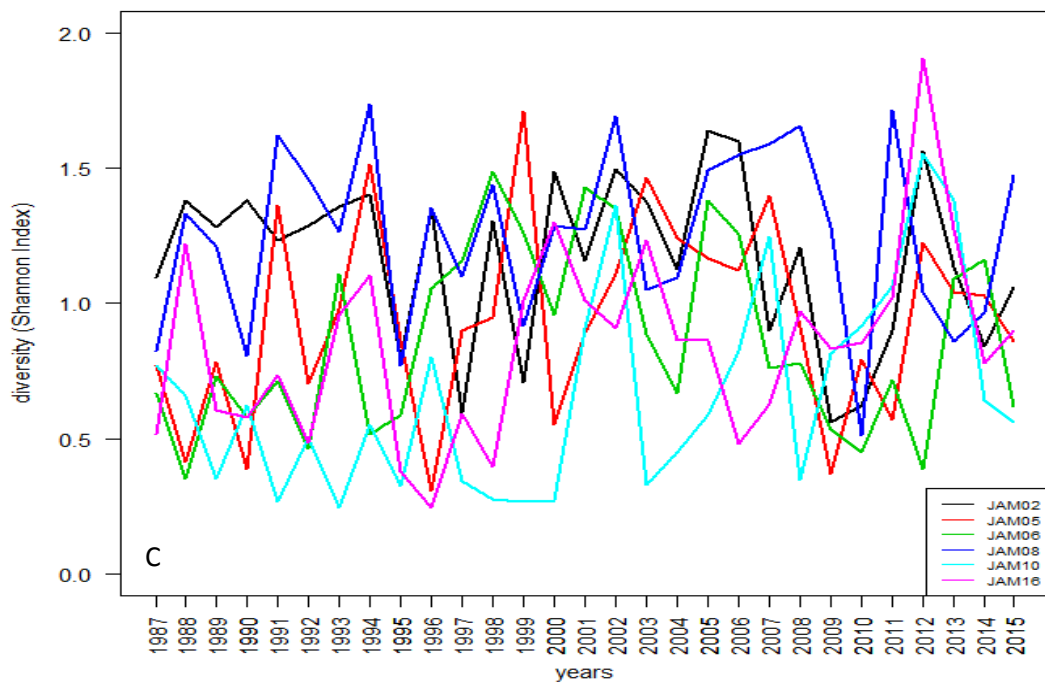
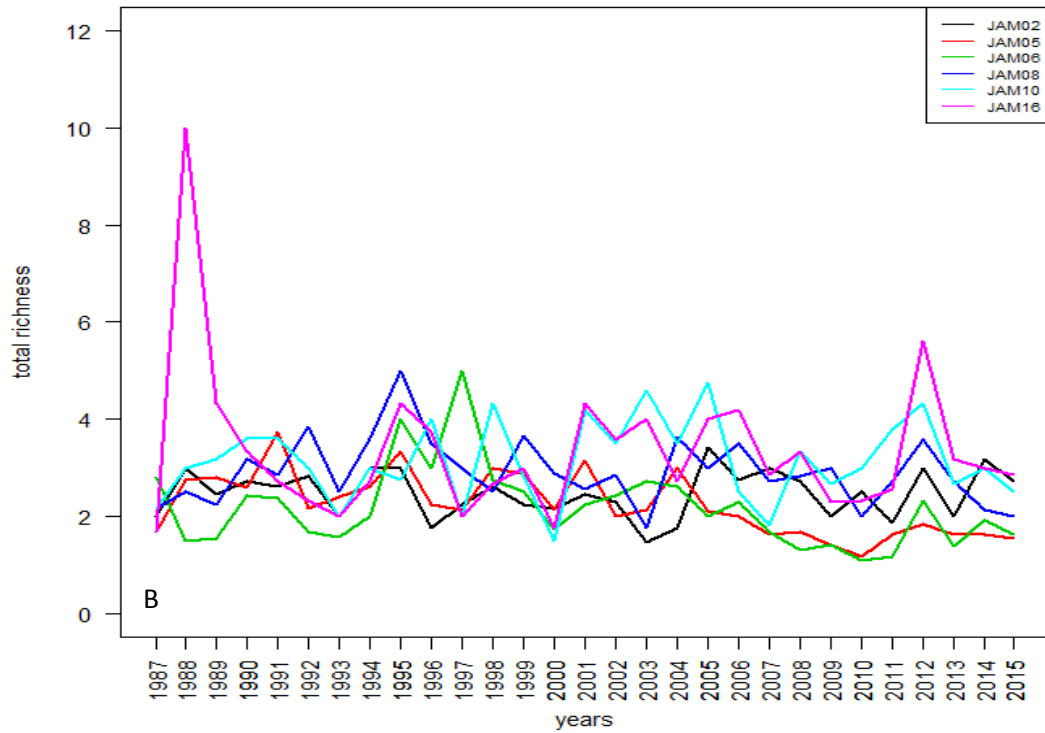


Figure 7. Temporal trend of total abundance (A), total richness (B), and diversity by Shannon index (C) during the period 1987-2015 for sampling stations 2 (JAM02), 5 (JAM05), 6 (JAM06), 8 (JAM08), 10 (JAM10) and 16 (JAM16). Stations 1, 17 and 22 were not included because they have several gaps in their temporal sampling.

3. Temporal Changes in the Fish Community Composition

The partition of the beta diversity (β_{SOR}) by Sørensen index for the temporal changes of the fish community in Jamaica Bay (Figure 8) was obtained for its two components nestedness (β_{SNE}) and turnover (β_{SIM}). The value of beta diversity calculated by the Sørensen index in the period 1987-2015 was 0.87. The contribution of turnover was 0.76 and the contribution of nestedness was 0.11. Therefore, the temporal changes in the fish community are explained mostly by substitution of some species by others (turnover) and not by species loss (nestedness).

The map of dissimilarities (distances between years) in the period 1987-2015 resulted from the multidimensional scaling by Bray-Curtis index, did not show a clear arrangement of these years (Figure 9). The distribution of the points (years) appears random. Nevertheless, years 1999, 2005 and 2012 are separated to the central east region of the map. The rest of the years remained in the center closely to each other indicating similar community composition. Additionally, the multidimensional scaling showing the species ordination by their dissimilarities, illustrated a random distribution of the species and not any relationship between species belonging to the same ecological characteristic (Figure 10). Therefore, there is not a specific temporal distribution of the species accounting for their categories. The MDS analysis carried out individually per station, to observe the temporal trajectory of the community during the term 1987-2015 (Figure 11), did not show a clear pattern of change in directions in the nine stations, indicating light inter-annual variability.

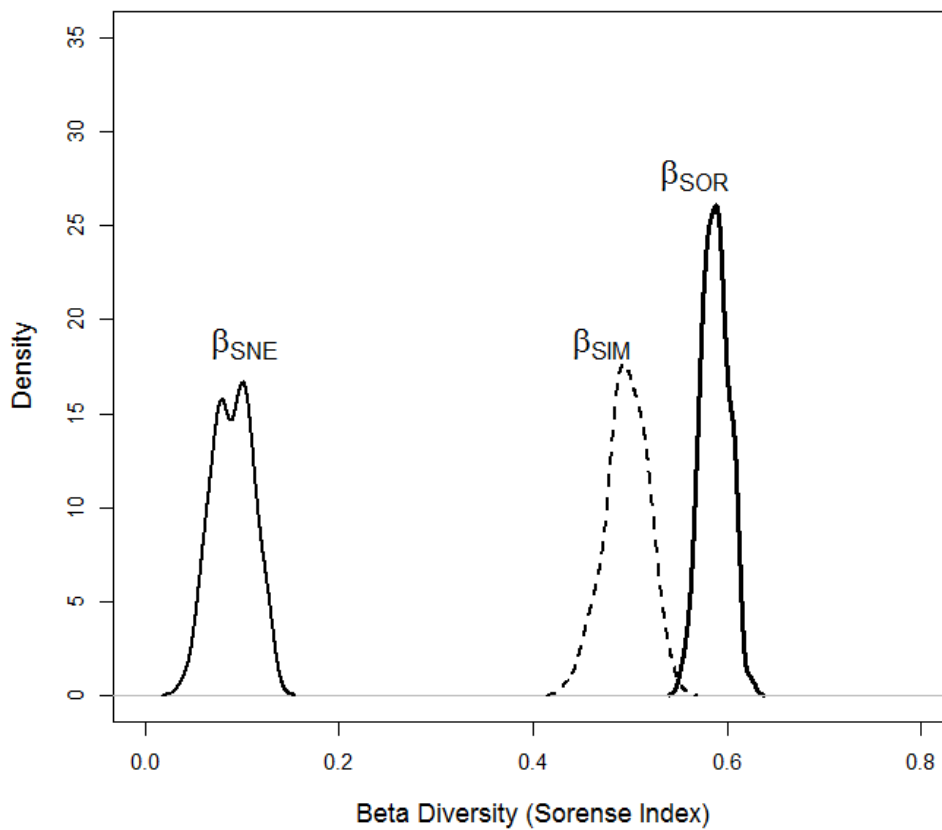


Figure 8. Density plot representing the partition of Beta Diversity calculated by Sørensen index ($\beta_{SOR} = 0.87$) into its components: Nestedness ($\beta_{SNE} = 0.11$) and Turnover ($\beta_{SIM} = 0.76$). The curve of density representing the turnover component is closer to the curve representing the total beta diversity than the curve of density for nestedness, indicating a higher contribution of turnover to beta diversity.

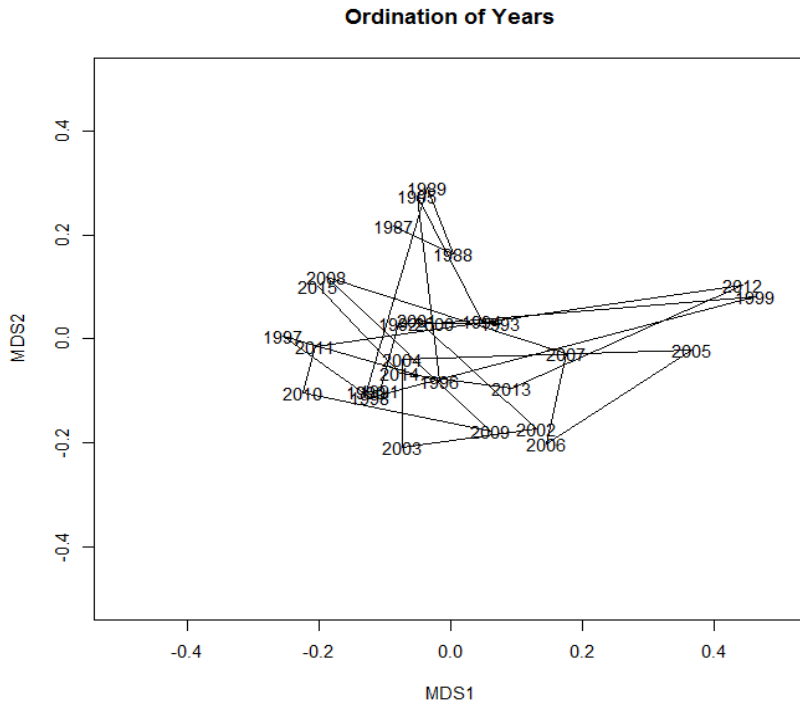


Figure 9. Multidimensional scaling (MDS) map by Bray-Curtis index showing the ordination of years from 1987 to 2015, accounting for years' species abundance and occurrence.

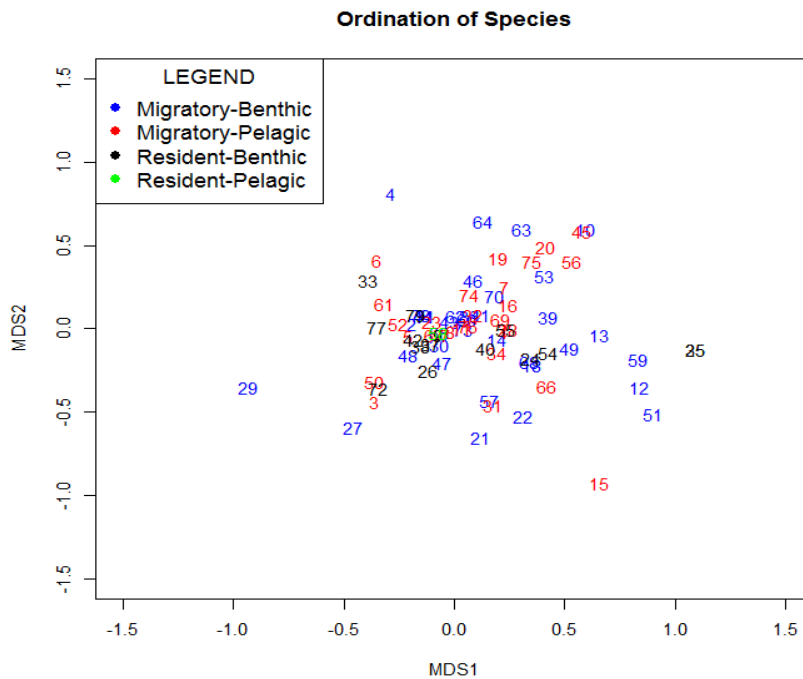
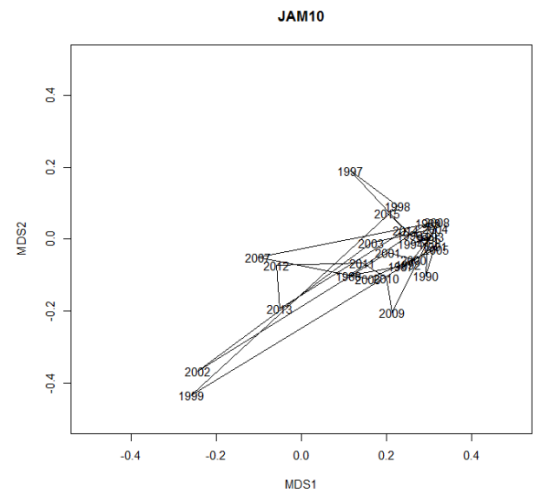
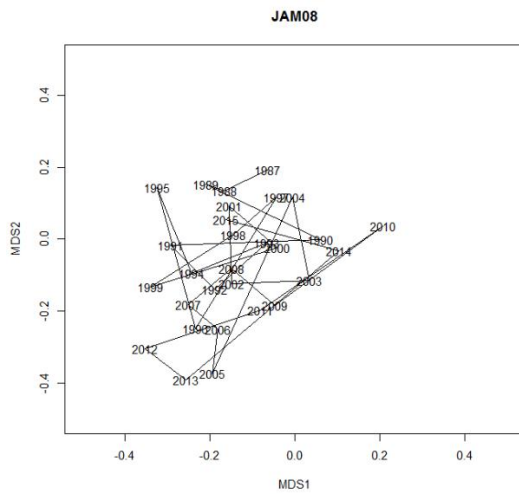
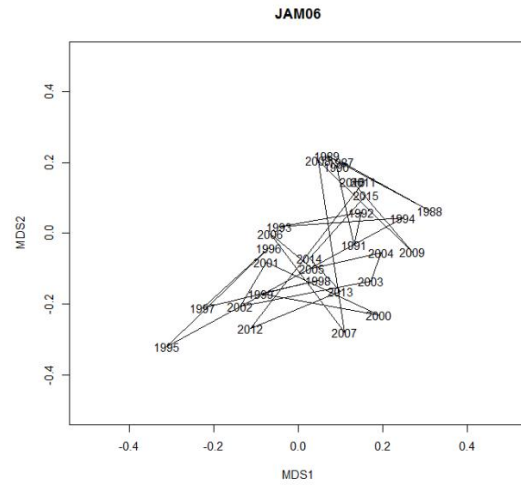
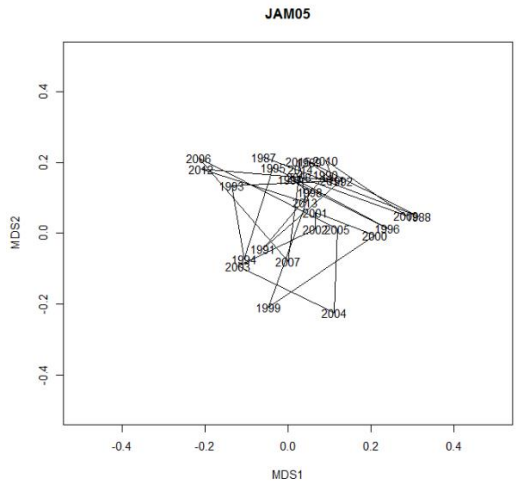
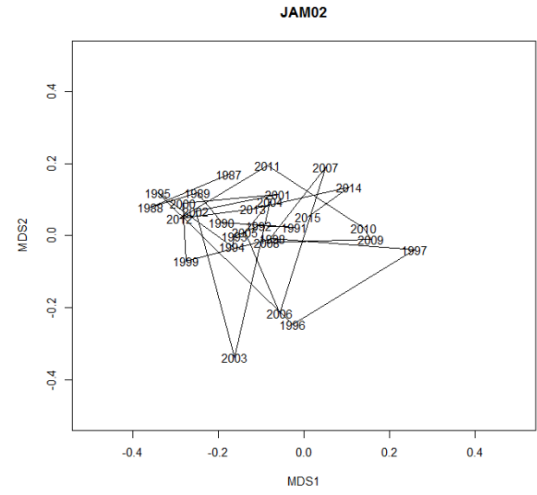
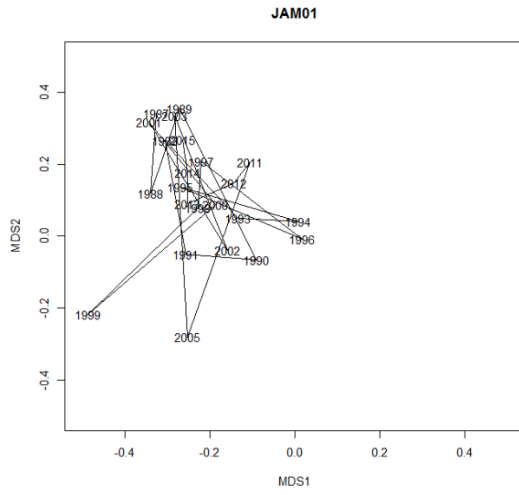


Figure 10. Multidimensional scaling (MDS) map by Bray-Curtis index showing the ordination of the 79 fish species from 1987 to 2015, accounting for species abundances and years of occurrence. Numbers in the graph represent the species (Supplementary Information Table S3) and colors the classification of the species by four categories (Migratory-Benthic, Migratory-Pelagic, Resident-Benthic and Resident-Pelagic).



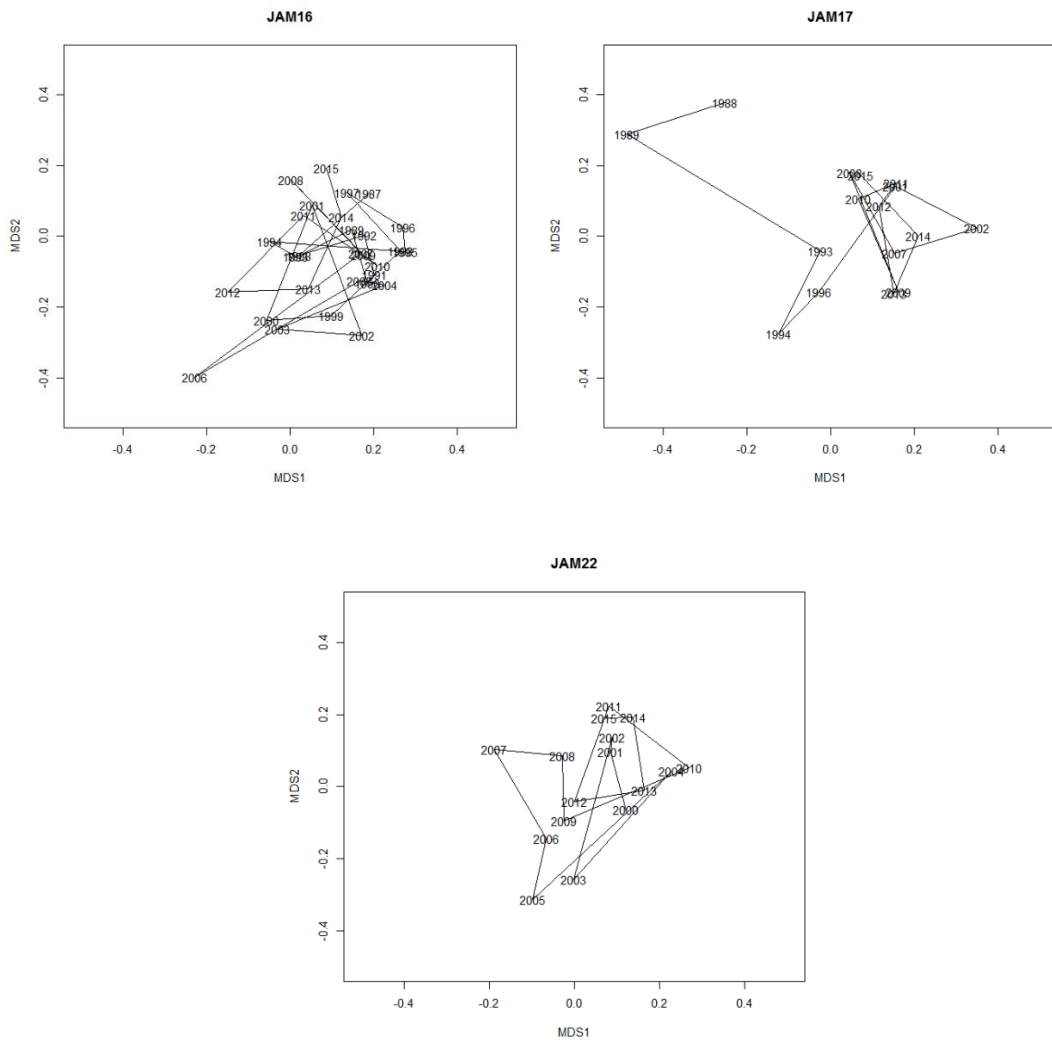


Figure 11. Multidimensional scaling (MDS) map by Bray-Curtis index showing the ordination of years from 1987 to 2015 for each station (Station 1 or JAM01, 2 or JAM02, 5 or JAM05, 6 or JAM06, 8 or JAM08, 10 or JAM10, 16 or JAM16, 17 or JAM17 and 22 or JAM22).

DISCUSSION

Temporal Trends in Species-Specific Abundance

From the 100 species of fishes previously identified in the bay by Solecki et al.

(2016), we found 79 species. U.S. Army Corps of Engineers (USACE, 2012) found

atlantic silverside to be the most prevalent species caught while seining shallow

water areas and killifish species was the second most prevalent near the shore in

Jamaica Bay. In a similar way, we reported these same two species as the most prevalent and abundant in the bay.

The abundance per species at the bay showed great interannual fluctuations along the years. Baumgartner et al. (1992) described these kinds of temporal fluctuations of fish populations and explained that this variability manifests itself as strings of years with high and low abundances and can arise from several processes such as species interactions, density dependence, and spatially explicit or age-structured population dynamics (Akçakaya et al., 2003). In addition, population variability could also be a consequence of environmental variations (Chavez et al., 2003). It has also been described that in most biotic time series, variability increases with the number of years included (Pimm and Redfern, 1988). Since there are many potential factors influencing population variability, it is not clear what specific factor could be responsible for the interannual fluctuations detected in our temporal analysis of the community of Jamaica Bay.

In addition of the strong patterns of interannual fluctuations in the total abundances at the bay for most species, 22% of them showed significant trends. From the 17 out of 79 species with significant trends, 76% were significantly positive and the other 24% were significantly negative. Nevertheless, in spite of these significant trends for the temporal abundance of species, our analysis did not detect any temporal significant trend for the total abundance of all species in the bay, suggesting that fish populations in Jamaica Bay might be limited by the carrying capacity of the ecosystems. Additionally, striped burrfish, seaboard goby, cunner, black drum,

skilletfish and bluespotted cornetfish were some of the species with significant positive trends in their temporal abundance, because their abundances were close to zero most of the years during the period 1987-2015 except in the last part of the sampling period. It is important to notice that the higher detectability of these species during the most recent years could be a result of an increased number of samplings by the end of the term, which increased the probabilities of capturing these rare species (Supplementary Information Figure S1).

Among the species with a significant positive trend, most of them (84%) corresponded to migratory species. Of these migratory species, 55% were benthic while 45% were pelagic. In contrast, all species that exhibited a significant negative trend corresponded to resident-benthic species. Thus, our results showed that some migratory species are increasing their use of the bay. Able (2005) mentions that the use of estuaries by some not estuarine obligate species (migratory according to our classification) might vary over a long temporal scale, especially when associated with climate change. As an example, the species atlantic croaker has expanded its use of estuaries in the central portion of the Middle Atlantic Bight, in the coast of U.S., in association with a general warming trend over the last decade (Able, 2005).

We detected a significant positive trend for the total abundance of migratory and pelagic species in the bay. Nevertheless, our generalized linear models, which tested the effect of both the use of the bay (migratory or resident) and the position in the water (pelagic and benthic) on the temporal trends of species, were not significant ($p > 0.05$). This result suggests that these ecological characteristics of fishes did not influence their temporal trends.

Spatial and Temporal Changes in the Fish Community Composition

In general, abundance, richness and diversity at each station fluctuated from 1987 to 2015 without an overall tendency to increase or decrease. These results suggest that the fish community in the bay has remained stable in both time and space. In addition, the absence of significant trends in the total abundance of species (the sum of the abundances of all species) at each station suggests that the number of individuals is limited by the ecosystem carrying capacity at this lower spatial scale. Importantly, the extreme high value of richness obtained for station 16 in 1988 should not be considered as reliable because it is a result of the richness standardization method. In 1988, station 16 was sampled only once with a record of 11 species.

Our results show that the temporal variation in community composition are explained mostly by species substitution (turnover) more than by species loss (nestedness). This means that the differences in community composition in different years might be explained as a result of some species been replaced by others and not because each community represents a subset of another. Since our database comprises a high number of species and years, the patterns in the community composition are very complex, challenging any attempt to understand how different ecological processes could be acting here.

In spite of all the human impacts in Jamaica Bay, our multidimensional scaling analysis illustrating the dissimilarities among years from 1987 to 2015 for the total

values of abundances in the bay, and for each of the nine stations, do not show a shift in direction during the 29-year-period. Nevertheless, the nine stations present three different types of temporal trajectories from 1987 to 2015. First, some stations show a very similar community composition among all years which is reflected in all years been grouped very close to each other. Second, on other stations, there is only one year that departs from the rest but returns to the central group. In the third type of trajectory, some stations show more than one year departing from the area that includes most of the years. We could consider this central area where most of the years are grouped as an equilibrium stage for the community. These results suggest that both temporarily (along the 29 years) and spatially (between stations), the community has remained very similar to each other. In the same way, the multidimensional scaling illustrating the ordination of the 79 fish species classified in Migratory-Benthic, Migratory-Pelagic, Resident-Benthic and Resident-Pelagic, confirmed the absence of shifts in the community composition. This is evidenced by the absence of any patterns of organization or aggrupation of the species by their ecological categories.

However, dramatic shifts in species composition have occurred in the northwest Atlantic, North Sea, and Gulf of Thailand in response primarily to fishing pressure and secondarily to changes in the marine climate (Hall, 1999). The species composition of the fish and invertebrate communities in Narragansett Bay and Rhode Island Sound, Rhode Island, which have faced many of the same challenges as Jamaica Bay, have changed dramatically since 1959 to 2005 (Collie et al., 2008). Ordination of the community data by nonmetric, multidimensional scaling using

Bray-Curtis index revealed that the shifts at Narragansett Bay and Rhode Island Sound began in the 1980s (Collie et al., 2008). Additionally, in Chesapeake Bay, another bay facing similar challenges as Jamaica Bay, Bilkovic (2011) compared fish community of dredged to undredged creeks in the Lynnhaven River, which flows into the bay, and obtained differences in species biomass among creeks, demonstrating the influence of anthropogenic alterations in shifting fish communities. Furthermore, Sobocinski et al. (2013) found a shift in species composition comparing data from two different periods, 1976-1977 and 2009-2011 in Chesapeake Bay. Moreover, O'Connor et al. (2012) detected changes of the fish community in the Hudson Estuary from 1974 to 2005. They found that these changes in the Hudson Estuary were correlated with local hydrology (freshwater flow and water temperature) and regional climate (the Atlantic Multidecadal Oscillation and the North Atlantic Oscillation).

Taking into consideration that most of the negative impacts on Jamaica Bay have been during the late 19th to the first half of the 20th Century, we could suggest that the analyzed period (from 1987 to 2015) is capturing a community already degraded that shifted from its original state before these monitoring efforts started. Collie et al. (2008) found that the fish community composition at Narragansett Bay and Rhode Island Sound began to change in the 1980s, analyzing a database of 47-year period. The shift detected in Narragansett Bay and Rhode Island Sound supports our interpretation that the deterioration of the fish community in Jamaica Bay could have occurred before the sampling in Jamaica Bay began.

Additionally, despite the environmental improvements experienced in Jamaica Bay during the last two decades, it is surprising that we did not observe any shift in its fish community during this period. Government agencies and nonprofits have restored more than 150 acres (60 ha) of salt marsh areas to compensate its losses (U.S. Army Corps and Engineers, 2016). Since mid-1990s, the nitrogen discharges into the bay have been reduced to 26,000 pounds per day from 50,000 pounds of nitrogen each day. Many projects have been developed to improve the water quality such as growth of ribbed mussels, artificial oyster bed structures, restoration of wetlands and green infrastructure practices. After more than 150 years suffering from anthropogenic impact and accelerated climate change, it is likely that more time should be required to trigger a positive change in the Jamaica Bay's communities which could indicate that the community is returning to a more natural state.

In addition to the hypothesis that we could be in presence of a degraded community that has not changed in the sampled years, there could be two other plausible alternative sceneries. First, the community could be resilient to the environmental changes occurred in the last three decades. This alternative hypothesis could be supported by the absence of any shift of the fish community after the hurricane Sandy in 2012 that impacted the area of Jamaica Bay with devastating consequences. Second, the internal dynamics at Jamaica Bay could be masked by the surrounding communities as a result of a possible strong connectivity among different zones in the area (i.e. Open Ocean and neighboring bays).

Future Directions

We propose to carry out a broader characterization of the biota of Jamaica Bay by including invertebrate groups such as crabs for which similar temporal data exists.

This study will not only contrast the results obtained for the fish community, but will also allow to study any relationship between benthic invertebrates (crabs) and migratory/resident benthic fishes. Additionally, we are interested in exploring the potential environmental drivers of the community fluctuations. The use of multivariate autoregressive models will allow to quantify the role of external (environmental) and internal (interspecific interactions) drivers on the temporal evolution of the composition of the Jamaica Bay's community.

CONCLUSIONS

In this study we analyzed the temporal and spatial trends related to abundance, richness and diversity and the temporal changes in the community composition of the fishes in Jamaica Bay from 1987 to 2015.

- We found that although most species showed strong patterns of interannual fluctuations in their abundance and some of them had significant positive or negative trends, the total abundance of fishes in the bay did not show a significant trend over the period. This result suggests that the biomass in the bay might be regulated by a limit in the carrying capacity of the ecosystems.

- Additionally, the significant positive or negative trends detected for some species are not determined by the differential use of the bay by fishes (migratory or resident) or their position in the water column (pelagic or benthic).
- We did not obtain any significant spatial (among sampling sites) or temporal (among years) shift of the fish community. The community composition was very similar among years and stations.
- The lack of shift in the fish community could be explained by three different alternative sceneries: 1) the community is already degraded, 2) the community is resilient to the environmental changes in the last three decades, or 3) the internal ecological dynamics of the community are masked by the surrounding communities.

REFERENCES

1. Able, K.W. 2005. A re-examination of fish estuarine dependence: Evidence for connectivity between estuarine and ocean habitats. *Estuarine Coastal and Shelf Science* 64: 5-17.
2. Akcakaya, H.R., J.M. Halley and P. Inchausti. 2003. Population level mechanisms for reddened spectra in ecological time series. *J. Anim. Ecol.* 72: 698–702. doi:10.1046/j.1365-2656.2003. 00738.x.
3. Baselga, A. 2010. Partitioning the turnover and nestedness components of beta diversity. *Global Ecology and Biogeography* 19:134-143.
4. Baselga, A. 2012. The relationship between species replacement, dissimilarity derived from nestedness and nestedness. *Global Ecology and Biogeography* 21:1223-1232.

5. Baselga, A. 2017 Partitioning abundance-based multiple-site dissimilarity into components: balanced variation in abundance and abundance gradients. *Methods in Ecology and Evolution* 8:799-808.
6. Baselga, A., D. Orme, S. Vileger, J. De Bortoli and F. Leprieur. 2018. Available at: <https://cran.r-project.org/web/packages/betapart/betapart.pdf>.
7. Baumgartner, T.R., A. Soutar and V. Ferreira-Bartrina. 1992. Reconstruction of the history of Pacific sardine and northern anchovy populations over the past two millennia from sediments of the Santa Barbara basin, California.
8. Bilkovic, D.M. 2011. Response of tidal creek fish communities to dredging and coastal development pressures in a shallow-water estuary. *Estuaries and Coasts* 34:129-147.
9. Briggs, P.T. and J.R. Waldman. 2002. Annotated list of fishes reported from the marine waters of New York. *Northeastern Naturalist* 9(1):47-80.
10. Chavez, F.P., J.L. Ryan, S.E. Lluch-Cota and M. Niquen. 2003. From anchovies to sardines and back: multidecadal change in the Pacific Ocean. *Science* (Washington, D.C.), 299: 217–271. doi:10.1126/science.1075880. PMID:12522241.
11. Collie, J. S., A. D. Wood and H. P. Jeffries. 2008. Long-term shifts in the species composition of a coastal fish community. *Canadian Journal of Fisheries and Aquatic Sciences* 65:1352–1365.
12. Gordon, A. L. and R. W. Houghton. 2004. The waters of Jamaica Bay: impact on sediment budget. *Proceedings: Jamaica Bay's disappearing marshes*. National Park Service, Gateway National Recreation Area, New York. p.18.
13. Hall, S.J. 1999. *The effects of fishing on marine ecosystems and communities*. Blackwell Science, Oxford, UK.
14. Handel, S.N., J. Marra, C.M.K. Kaunzinger, V.M. Bricelj, J. Burger, R.L. Burke, M. Camhi, C.P. Colón, O.P. Jense, J. LaBelle, H.C. Rosenbaum, E.W. Sanderson, M.D. Schlesinger, J.R. Waldman and Ch.B. Zarnoch. 2016. Ecology of Jamaica Bay: History, Status, and Resilience. In: E.W. Sanderson, W.D. Solecki, J.R. Waldman, and A.S. Parris (Eds.), *Prospects for Resilience: Insights from New York City's Jamaica Bay*, 91:116. Washington, DC: Island Press.
15. Legendre, P. and L.F. Legendre. 2012. *Numerical ecology* (Vol. 24). Elsevier. Amsterdam.
16. National Academy of Sciences and National Academy of Engineers. 1971. *Jamaica Bay and Kennedy Airport*. Report of the Jamaica Bay Environmental Study Group. Volume II. Port Authority of New York and New Jersey. Washington, D.C.
17. New York City Department of Environmental Protection (NYCDEP). 1994. *Jamaica Bay comprehensive watershed management plan*. New York City Department of Environmental Protection. New York, NY.

18. New York City Department of Environmental Protection (NYCDEP). 2007. Jamaica Bay Watershed Protection Plan. Accessed at: http://www.nyc.gov/html/dep/html/harborwater/jamaica_bay.shtml.
19. New York City Department of Environmental Protection (NYCDEP). 2014. Jamaica Bay Watershed Protection Plan. Accessed at: http://www.nyc.gov/html/dep/pdf/jamaica_bay/jbwpp_update_10012014.pdf.
20. New York City Department of Environmental Protection (NYCDEP). 2016. Jamaica Bay Watershed Protection Plan. Accessed at: http://www.nyc.gov/html/dep/pdf/jamaica_bay/jbwpp_update_10012016.pdf.
21. O'Connor, M.P., F. Juanes and K. McGarigal. 2012. Findings on American Shad and Striped Bass in the Hudson River Estuary: a fish community study of the long-term effects of local hydrology and regional climate change. *Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science* 4: 327-336.
22. Oksanen, J. 2015. *Multivariate Analysis of Ecological Communities in R: vegan tutorial*. Version 2.3–0. Documentation for R: a language and environment for statistical computing.
23. Oviatt, C.A. and S.W. Nixon. 1973. The demersal fish of Narragansett Bay: An analysis of community structure, distribution and abundance. *Estuarine and Coastal Marine Science* 1:361-378.
24. Pimm, S.L. and A. Redfern. 1988. The variability of population densities. *Nature (London)*, 334: 613–614. doi:10.1038/334613a0.
25. R Development Core Team, 2010. *R: A Language and Environment for Statistical Computing*. R: Vienna. Available at: <http://www.r-project.org>.
26. Sobocinski, K.L., R.J. Orth, M.C. Fabrizio and R.J. Latour. 2013. Historical comparison of fish community structure in lower Chesapeake Bay Seagrass Habitats. *Estuaries and Coasts* 36: 775-794.
27. Solecki, W.D., E.W. Sanderson, J.R. Waldman and A.S. Parris. 2016. Why Prospects for Resilience for Jamaica Bay? In: E.W. Sanderson, W.D. Solecki, J.R. Waldman, and A.S. Parris (Eds.), *Prospects for Resilience: Insights from New York City's Jamaica Bay*, 3:19. Washington, DC: Island Press.
28. Swanson, L., M. Dorsch, M. Giamperi, P. Orton, A.S. Parris and E.W. Sanderson. 2016. Dynamics of the Biophysical Systems of Jamaica Bay. In: E.W. Sanderson, W.D. Solecki, J.R. Waldman, and A.S. Parris (Eds.), *Prospects for Resilience: Insights from New York City's Jamaica Bay*, 91:116. Washington, DC: Island Press.
29. Trust for Public Land and the New York City Audubon Society. 1987. *Buffer the Bay: A survey of Jamaica Bay's Unprotected Open Shoreline and Uplands*. New York: The Trust for Public Land.

30. U.S. Army Corps of Engineers (USACE). 2012. JBERRT-Jamaica Bay Ecosystem Research and Restoration Team. Final Report. Tanacredi, John T., Martin P. Schreibman, and George W. Frame (Eds.) Staten Island, New York: National Park Service Division of Natural Resources.
31. U.S. Army Corps of Engineers (USACE). 2016. Jamaica Bay Marsh Islands. Accessed _____ at: <http://www.nan.usace.army.mil/Missions/CivilWorks/ProjectsInNewYork/EldersPointJamaicaBaySaltMarshIslands.aspx>.
32. U.S. Fish and Wildlife Service (USFWS). 1997. Significant habitats and habitat complexes of the New York Bight watershed. Southern New England – New York Bight Coastal Ecosystems Program. Charlestown, Rhode Island.
33. Waldman, J.R. 2006. The diadromous fish fauna of the Hudson River: life histories, conservation concerns, and research avenues. Pages 171-188 in J.S. Levinton and J.R. Waldman, editors. The Hudson River Estuary, Cambridge University Press.
34. Waldman, J.R. 2008. Research opportunities in the natural and social sciences at the Jamaica Bay Unit of the Gateway National Recreation Area. Jamaica Bay Institute, National Park Service, Brooklyn, NY. 77p.
35. Waldman, J.R., T. Lake and R.E. Schmidt. 2006. Biodiversity and zoogeography of Hudson Estuary Fishes. American Fisheries Society Symposium Series 51:129-150.
36. Waldman, J. and W. Solecki. 2018. The great transformation: Exploring Jamaica Bay in the late 19th and early 20th centuries through newspaper accounts. Natural Resource Report NPS/NCBN/NRR—2018/1607. National Park Service, Fort Collins, Colorado.

SUPPLEMENTARY INFORMATION

Table S1. Total of number of samplings per stations (Stations 1, 2, 5, 6, 8, 10, 16, 17 and 22) and per years from 1987 to 2015 in Jamaica Bay.

Years	Station 1 (JAM01)	Station 2 (JAM02)	Station 5 (JAM05)	Station 6 (JAM06)	Station 8 (JAM08)	Station 10 (JAM10)	Station 16 (JAM16)	Station 17 (JAM17)	Station 22 (JAM22)
1987	3	7	6	5	6	6	6	0	0
1988	7	6	4	6	6	5	1	4	0
1989	4	9	5	9	8	6	3	1	0
1990	5	7	5	7	6	5	3	0	0
1991	7	8	4	8	7	5	7	0	0
1992	2	6	6	6	6	6	6	0	0
1993	3	7	5	7	6	5	7	1	0
1994	5	6	8	8	5	8	7	2	0
1995	4	4	3	2	3	4	3	0	0
1996	4	8	4	1	4	3	4	1	0
1997	3	8	7	1	6	5	7	0	0
1998	6	8	4	8	6	3	6	0	0
1999	8	8	8	6	6	6	5	0	0
2000	7	12	7	11	8	8	8	0	6
2001	3	11	7	8	9	5	3	1	10
2002	1	10	6	7	7	6	7	1	9
2003	2	13	7	7	13	5	5	0	12
2004	0	12	6	8	8	6	7	0	12
2005	1	7	10	12	7	4	5	0	10
2006	0	8	11	10	6	6	5	0	7
2007	0	8	11	13	7	5	7	3	9
2008	0	7	13	13	6	6	6	6	7
2009	0	7	12	12	6	6	7	6	3
2010	0	6	12	12	6	5	6	5	6
2011	1	7	13	12	7	5	7	6	6
2012	5	7	12	12	7	6	5	6	5
2013	4	4	13	13	7	6	6	7	7
2014	8	6	13	12	7	7	7	7	5
2015	9	7	13	13	6	7	7	6	7

Table S2. Total abundance per species during the period 1987-2015. Fishes are ordered from species with the highest values of abundances to the lowest. A column with the classification of the fishes according to their use of the bay (Migratory or Resident) and their position in the water column (Benthic or Pelagic) is shown.

Common Name	Total Abundance	Classification
Silverside spp.	115807.2	Resident-Pelagic
Killifish spp.	32830.1	Resident-Benthic
Atlantic menhaden	27892.2	Migratory-Pelagic
Bay anchovy	11952.9	Migratory-Pelagic
Winter flounder	3879.2	Resident-Benthic
Atlantic herring	2921.0	Migratory-Pelagic
Bluefish	2541.2	Migratory-Pelagic
Striped bass	1793.9	Migratory-Pelagic
Northern kingfish	683.1	Migratory-Benthic
White mullet	584.4	Migratory-Pelagic
Northern pipefish	456.4	Resident-Benthic
Striped searobin	433.5	Migratory-Benthic
Blueback herring	276.0	Migratory-Pelagic
Northern puffer	238.5	Migratory-Benthic
Alewife	191.9	Migratory-Pelagic
Windowpane flounder	179.3	Migratory-Benthic
Blackfish (tautog)	134.2	Migratory-Benthic
Striped mullet	119.9	Migratory-Pelagic
Spot	109.3	Migratory-Benthic
Fourspine stickleback	104.6	Resident-Benthic
Inshore lizardfish	98.6	Migratory-Benthic
Smallmouth flounder	96.2	Migratory-Benthic
Summer flounder	69.4	Migratory-Benthic
White perch	66.9	Resident-Benthic
Crevalle jack	63.1	Migratory-Pelagic
Striped anchovy	62.9	Migratory-Pelagic
Atlantic needlefish	56.1	Migratory-Pelagic
Northern searobin	48.6	Migratory-Benthic
American eel	27.8	Migratory-Benthic
Grubby sculpin	25.8	Migratory-Benthic
Naked goby	24.2	Resident-Benthic
Oyster toadfish	16.0	Migratory-Benthic
Scup	14.3	Migratory-Benthic
Northern stargazer	13.6	Migratory-Benthic
Lined seahorse	11.4	Resident-Benthic
Northern sennet	9.5	Migratory-Pelagic
Spotted hake	7.8	Migratory-Benthic
Spanish mackerel	7.6	Migratory-Pelagic
Black sea bass	7.3	Migratory-Benthic

Common Name	Total Abundance	Classification
Pinfish	7.3	Migratory-Benthic
Weakfish	5.9	Migratory-Pelagic
Sand lance spp.	5.8	Migratory-Pelagic
Pollock	5.8	Migratory-Pelagic
Seaboard goby	5.1	Resident-Benthic
Silver perch	4.7	Migratory-Benthic
Permit	4.7	Migratory-Benthic
Atlantic tomcod	4.6	Resident-Benthic
Striped burrfish	3.9	Migratory-Benthic
Threespine stickleback	3.1	Resident-Benthic
Butterfish	2.5	Migratory-Pelagic
Sheepshead minnow	2.4	Resident-Benthic
Skilletfish	2.0	Migratory-Benthic
Halfbeak (silverstripe)	1.9	Migratory-Pelagic
Cunner	1.9	Resident-Benthic
Black drum	1.7	Migratory-Benthic
Silver hake	1.4	Migratory-Pelagic
Bluespotted cornetfish	1.4	Migratory-Benthic
Atlantic mackerel	1.2	Migratory-Pelagic
Trunkfish	1.1	Migratory-Benthic
Wahoo	1.0	Migratory-Pelagic
Horse-eye jack	0.8	Migratory-Pelagic
Feather blenny	0.8	Resident-Benthic
American shad	0.5	Migratory-Pelagic
Hickory shad	0.5	Migratory-Pelagic
Hogchoker	0.5	Resident-Benthic
Cobia	0.3	Migratory-Pelagic
Gray snapper	0.3	Migratory-Benthic
Atlantic cod	0.3	Migratory-Benthic
Blue runner	0.3	Migratory-Pelagic
Red hake	0.3	Migratory-Benthic
Spotfin mojarra	0.3	Migratory-Benthic
Cownose ray	0.2	Migratory-Benthic
Inquiline snailfish	0.2	Resident-Benthic
Mottled mojarra	0.2	Migratory-Benthic
Bandtail puffer	0.2	Migratory-Benthic
Conger eel	0.2	Migratory-Benthic
Spotfin butterflyfish	0.1	Migratory-Benthic
Gizzard shad	0.1	Migratory-Pelagic
Fourspot flounder	0.1	Migratory-Benthic

Table S3. Number and name of the species represented in the multidimensional scaling map by Bray-Curtis index (Figure 9).

Order	Common Name	Order	Common Name
1	Alewife	41	Northern kingfish
2	American eel	42	Northern pipefish
3	American shad	43	Northern puffer
4	Atlantic cod	44	Northern searobin
5	Atlantic herring	45	Northern sennet
6	Atlantic mackerel	46	Northern stargazer
7	Atlantic menhaden	47	Oyster toadfish
8	Atlantic needlefish	48	Permit
9	Atlantic tomcod	49	Pinfish
10	Bandtail puffer	50	Pollock
11	Bay anchovy	51	Red hake
12	Black drum	52	Sand lance spp.
13	Black sea bass	53	Scup
14	Blackfish (tautog)	54	Seaboard goby
15	Blue runner	55	Sheepshead minnow
16	Blueback herring	56	Silver hake
17	Bluefish	57	Silver perch
18	Bluespotted cornetfish	58	Silverside spp.
19	Butterfish	59	Skilletfish
20	Cobia	60	Smallmouth flounder
21	Conger eel	61	Spanish mackerel
22	Cownose ray	62	Spot
23	Crevalle jack	63	Spotfin butterflyfish
24	Cunner	64	Spotfin mojarra
25	Feather blenny	65	Spotted hake
26	Fourspine stickleback	66	Striped anchovy
27	Fourspot flounder	67	Striped bass
28	Gizzard shad	68	Striped burrfish
29	Gray snapper	69	Striped mullet
30	Grubby sculpin	70	Striped searobin
31	Halfbeak (silverstripe)	71	Summer flounder
32	Hickory shad	72	Threespine stickleback
33	Hogchoker	73	Trunkfish
34	Horse-eye jack	74	Wahoo
35	Inquiline snailfish	75	Weakfish
36	Inshore lizardfish	76	White mullet
37	Killifish spp.	77	White perch
38	Lined seahorse	78	Windowpane flounder
39	Mottled mojarra	79	Winter flounder
40	Naked goby		

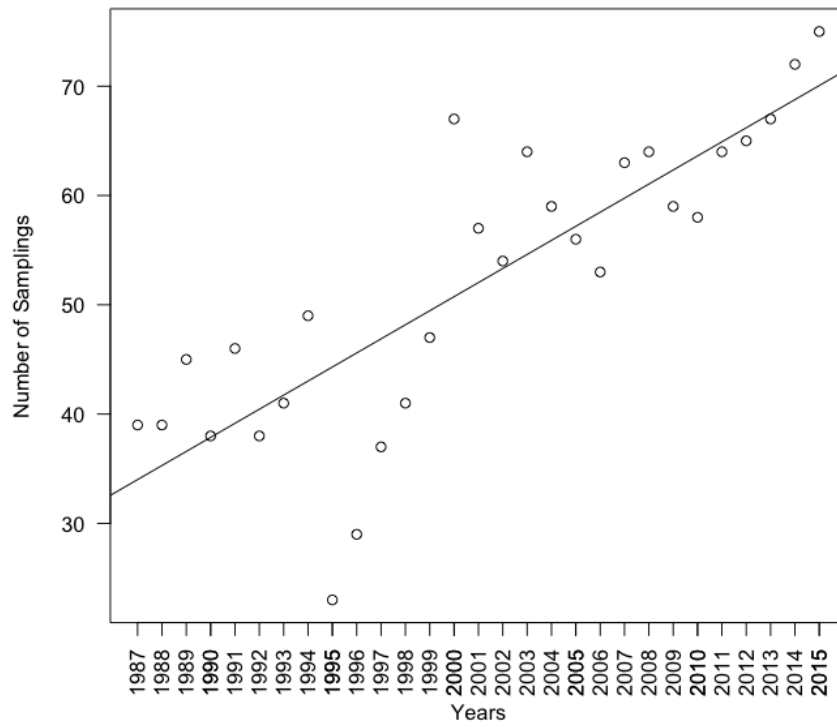


Figure S1. Scatter plot illustrating the temporal fluctuations of the total number of samplings in Jamaica Bay during the period 1987-2015. A strong increase in the number of samplings along the years was observed.