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Cover Photograph: East River Fishes and the Manhattan Skyline. Fish species, left to right, are Atlantic Silverside, Feather Blenny, Striped Bass, Summer Flounder, Spotted Hake, Black Sea Bass, Cunner, Bluefish, Atlantic Tomcod, Northern Puffer, Oyster Toadfish, and Striped Sea Robin. Feather Blenny Photograph © Devin M. Gorsen; Atlantic Tomcod Photograph © Mike Chen; Striped Bass Photograph © Christopher D. Girgenti; Oyster Toadfish Photograph © Lhana E.R. Ormenyi. All Other Photographs © Peter J. Park. All fishes were photographed in 2019 within the East River strait, New York City, New York.

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New York City East River Fish Species Inventory and Emergence of a Unique Fish Community Science Network

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Abstract - In 2019, a network of environmental education organizations formed the East River Ichthyological Alliance (ERIA) to study fish diversity in New York City’s East River strait. Between 1 April and 1 December 2019, total of 47 fish species comprising 9,279 individual fish were recorded from seining, angling, trapping, castnetting, dipnetting, and field observation. For analytical convenience, the strait was partitioned into 11 geographic zones. Species richness by zone was positively associated with number of sampling “sessions”, a simplistic proxy for effort. Independent of number of “sessions”, abundance of individuals caught was positively associated with total number of species caught. A second-order curvilinear relationship explained species richness and number of individuals caught in the strait. Diversity indices and rank abundance curves revealed that zones varied substantially in richness, abundance, and evenness. Inclusion of archived data from 2009 to 2018 raised the fish species inventory total to 58 species, of which 9 were tropical strays. Recommendations to improve data accuracy and ecological analysis are provided.

Introduction

Background on the East River Strait

New York City’s East River runs ~25 km from the northern edges of the Upper New York Harbor to the western reaches of the Long Island Sound. Despite its name, the waterway is a tidal strait and not a true river. It lies at the heart of one of the most culturally, historically, and ecologically diverse estuaries in the world. It is bordered by 4 of New York City’s 5 boroughs (Brooklyn, Manhattan, Queens, and the Bronx), crossed by 7 bridges, and overlaid by multiple automobile and subway tunnels. The East River has a complicated history of dynamic boom and bust periods for marine wildlife, with recent years showing improving conditions with deindustrialization (Hurley 1994, O’Neil et al. 2016, Steinberg 2014, Stinnette et al. 2018, Waldman 2013).

The East River strait is a drowned river valley, formed nearly 11,000 years ago by the retreat of the Wisconsin glaciers, the deposition of glacial debris, and subsequent inundation from rising seas. As sea levels rose, its estuarine substrate was formed by assorted glacial moraine, fine sediments, and landward erosion (Levinton and Waldman 2006). It is divided into an upper section and lower section by the Hell Gate, which restricts the water’s flow through its narrow passages (Li et al. 2018).

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The East River strait has high turbidity, substantial variations of tides, and variable bathymetry. Turbidity is characteristically high in the strait, resulting in low productivity or chlorophyll levels (a proxy for phytoplankton), which may account for curiously low rates of eutrophication (Li et al. 2018). Tides of the East River strait are distinct from, yet influenced by, both the Long Island Sound and New York Harbor tidal waves. The general flow is toward Long Island Sound. Differences exist between the upper and lower reaches of the strait because of geography. At the Battery, the difference between low and high tide can be 1.34 m (4.4 ft), while differences between low and high tide at the Long Island Sound end can range up to 2.19 m (7.2 ft) (Waldman 2013). Tidal flows are most rapid in the lower reaches with 3 m/s (9.84 ft/s) flows near Hell Gate, while the upper reaches have a maximum flow of ~1 m/s (3.28 ft/s) (Li et al. 2018). The average mid-channel depth is 10.67 m (35 ft), while soundings as deep as 32.92 m (108 ft) exist (NOAA 2020). Seven distinct islands, both natural and human-made, exist within the East River strait basin. Human-induced changes to the shoreline and river bottoms have significantly shaped geographic features. As the city developed, natural soft shorelines were transformed into mostly vertical bulkheads throughout the length of the strait. Dredging, historic piers, deposition of excavated material, and other human-caused changes have created a distinctly urban habitat (Hurley 1994, Platt 2009, Roebig et al. 2012, Steinberg 2014, The City of New York 2005, Waldman 2013, Yozzo et al. 2004).

East River Ichthyological Alliance (ERIA)

In 2019, realizing the potential to be gained from enhanced research and knowledge specifically of the East River strait's fishery, a group of dedicated estuarine educators and researchers joined to form the East River Ichthyological Alliance (ERIA). Although only in its first year, ERIA represents a first for the East River strait. Stakeholders from throughout the strait have gathered around a singular goal with dual purposes. The goal is to develop a better understanding of the underwater life in the East River strait to serve as a proxy for ecological health and support increased engagement with its resources. The purposes are to facilitate community-based research and public outreach. The work presented here represents a summary of fish data collected by ERIA in 2019.

In this work, we use the term "community science", which, in the literature, has been defined both in a broad-sense (Cooper et al. 2007) and a narrow-sense (Charles et al. 2020). While both definitions are equally important and valid, we adopt Cooper et al.'s (2007) definition of "community science" as a broad term for science involving the public that encompasses a variety of research models where professionals and public participants work together to achieve research and education goals. The methods employed in the present work ranged from minimal professional research oversight (e.g., fishing clinics, recreational angling) to research models where scientists supervised public participants who assisted primarily in data collection (e.g., public seining events). The latter research model is commonly referred to as "citizen science", but this established term is value laden and necessitates continual context-dependent clarification (Eitzel et al. 2017), and, thus, we use the term "community science" in this work.

History of Industry and Environmental Protection in the East River Strait

Historical evidence of indigenous peoples' use of the East River strait for fishing, shellfish harvesting, and transport abounds (Boyle 1969, Burrows and Wallace 1999, Sanderson 2013, Waldman 2013). Streams and tidal creeks along the shores provided a nursery habitat for young fish species and connected the terrestrial and freshwater habitats with the tidal

strait. Early European accounts of the East River strait describe being able to walk 12 ft out into the water and still see pebbles on the river bottom (Steinberg 2014). Sharks, whales, seals, and other marine predators were familiar sights for early New Yorkers. These species existed because of ample food supplies of their prey, including *Brevoortia tyrannus* Latrobe (Atlantic Menhaden), *Anguilla rostrata* Lesueur (American Eel), and *Crassostrea virginica* Gmelin (Eastern Oyster) (Boyle 1969, Waldman 2017).

The 20th century brought increased development and industry to the shores and tributaries of the East River strait. As the city developed around the waterway, human activity began to degrade water quality. Sewage, first from buckets and later in sewer pipes, drained into the waters. Floating garbage in the city was seen as far as 15 mi off-shore, and there were accounts of children swimming neck-deep in sewage from the city's floating baths off of East 96th Street (Waldman 2013). Currently, combined sewage overflows (CSOs) are one of the most significant sources of pollution in the East River strait, accounting for the most substantial contributions of pathogens and marine debris. Combined impacts from pollution and overharvesting led to precipitous declines in the East River strait's underwater life, both for species composition and health. In general, industrial development along the East River strait is associated with discharges and changes in the chemistry of the water that contributed to stress of underwater communities (O'Neil et al. 2016). Before the implementation of the 1972 Clean Water Act, reports of fish with fin rot or unusual growths or fish die-offs in the East River strait were common (O'Conner 1976, Waldman 2013). Since then, water conditions in the East River strait have generally improved. Stricter discharge regulations and fewer industrial processes along the river have meant that water quality has had the potential to improve living conditions of marine organisms that breed, grow, and reside in the strait (Brosnan and O'Shea 1996, New York City Environmental Protection 2018, O'Neil et al. 2016, Taillie et al. 2020).

Throughout the East River strait's history, people have sought to use its resources. The strait and New York Harbor represent the most significant components of public space in the city. Historically, highways and fences built up around the strait diminished public access and compounded issues facing public engagement. More recently, waterfront parks, boating organizations, anglers, and others who hope to have more connection with the water have proliferated along the East River strait. Ancient vestiges of previous waterfront use, such as piers, have been given new life as structured habitat for marine organisms (e.g., ecological restoration, waterfront redevelopments), creating pockets of fish biodiversity (Buckley 1982, Grothues and Able 2020).

Dedicated environmental groups throughout the East River strait have been implementing public programs, including education for area residents, to give the public a better understanding of and a closer connection to the East River strait. Connecting residents to the culture, history, geology, and biology of the river is recognized as an invaluable tool in supporting stewardship and cultivating advocates for the health of the system. This inspiring waterway, which helped build New York City through its active maritime role, including having over 40 piers and being home to the Fulton Fish Market, and yet fell into an extensive period of neglect, is now rebounding in unthought-of and remarkable ways, driven by an increased understanding of the East River strait and its environment (O'Neil et al. 2016, Steinberg 2014). Despite these gains, much is still unknown about the strait and how it has changed over time. Detailed information on the health and makeup of its current fisheries, underwater habitat, and water quality is minimal at best. Improved understanding of these interacting elements is the goal of our East River environmental education and community science network.

Field-site Description

East River Fish Data Contributors

Fish data for this work were acquired during community science events (e.g., fishing clinics, seining), non-public programs (e.g., school field trips, camps), or individual recreational activity (e.g., angling) between 1 April 2019 and 1 December 2019. Data were contributed by ERIA environmental educators from 9 organizations: Alley Pond Environmental Center (APEC), Battery Park City Authority (BPCA), Brooklyn Bridge Park Conservancy (BBP), City Parks Foundation–Coastal Classroom (CPFCC), Lower East Side Ecology Center (LESEC), Nyack College, New York Office of Parks, Recreation and Historic Preservation (NYSOPRHP), New York State Department of Environmental Conservation (NYSDEC) I FISH NY program (Region 2 Office), and Randall’s Island Park Alliance (RIPA) (Table 1). For-hire fishing operation contributors included Capitol Princess Fishing Charters (Manhattan, NY), Never Enough Fishing Charters (Flushing, NY), and Reel Mayhem Fishing Charters (City Island, NY). Community science events ranged from non-public programs (e.g., classes, school field trips, internship programs) organized by environmental education organizations to city-wide public fish counts organized by the NYSDEC and Lamont–Doherty Earth Observatory. The latter were primarily the World Science Festival Great Fish Count in June (WSF et al. 2019), NYSDEC Great Fish Count in August (NYSDEC 2020b), and Day in the Life of the Hudson and Harbor in October (NYSDEC and LDEO 2019) events. Other data contributions came from recreational anglers, iNaturalist.org observations, and Hudson River Almanac entries (NYSDEC 2020c), all of which were confirmed with follow-up correspondence and photographs of specimens.

ERIA East River Study Zones

For convenience of data acquisition and discussion, the East River strait was divided into 11 physical zones (Fig. 1) based on 3 general criteria: (i) location of an environmental education organization study site (Table 1), (ii) boundaries identified by conspicuous human-made landmarks, and (iii) presence of public access (e.g., city park, state park, marina). These zones were not originally intended to separate ecologically-contrasting habitats. Without evidence available to the contrary, all 11 zones were assumed to have similar fish species richness values and assemblages. Each zone does generally have similar benthic substrate of sand, mud, and rocks and experiences considerable currents during tide changes. However, the lower region of the strait is narrower with generally faster current speeds, while the upper region is wider, has many more coves, and includes a zone with a relatively undisturbed marsh area.

The 11 zones, north to south, were described as follows: Zone 1, studied by APEC, connected the East River strait with Western Long Island Sound and generally encompassed Little Bay (east of Throgs Neck Bridge) up to Fort Totten Park; Zone 2, studied by Nyack College, was between the Whitestone Bridge and Throgs Neck Bridge; Zone 3, also studied by Nyack College, was between the eastern edge of Rikers Island (but did not include Rikers Island) and Whitestone Bridge. This zone also had access to 3 tributaries (Bronx River, Westchester Creek, and Flushing Creek); Zones 4a and 4b surrounded Randall’s Island and converged on the island’s southern edge and were labelled as such because these 2 zones share the same latitude. Zone 4a was bordered by the eastern tip of Rikers Island (this zone included Rikers Island) and the RFK Bridge, specifically the bridge’s western and southern aspects. This zone included Hell Gate Bridge and access to the Bronx Kill. This area was not studied by an environmental education organization, but data were contributed by recreational anglers. Zone 4b, studied by RIPA, was the southern portion of

Table 1. Environmental Education Organizations of the East River and Their Fish Programs. Total numbers for fish-focused programs in 2019 are shown for Public Programs and Nonpublic Programs. Public Programs were public community science events (e.g., fishing clinics, fish counts). Nonpublic Programs included on-site classes, school field trips, or internship programs that featured fishing, seining, and/or trapping. Event types for programs were seining (S), fishing clinics (F), or trapping (T). For a description of East River zones, see Figure 1.

Organization	Location(s)	Zone(s)	Public Programs	Nonpublic Programs	No. of Participants	Event Type
Alley Pond Environmental Center	Little Bay Park	1	6	1	80	S
Battery Park City Authority	Robert F. Wagner Jr. Park	10	3	15	2,565	F
Brooklyn Bridge Park Conservancy	Brooklyn Bridge Park	9	8	14	1,388	S, F, T
City Parks Foundation - Coastal Classroom	Hallett's Cove Beach	5	0	8	282	S
Lower East Side Ecology Center	John V. Lindsay East River Park	7, 8	11	7	850	F, T
New York Office of Parks, Recreation, and Historic Preservation	Gantry Plaza State Park	6	22	2	1,664	F, T
New York State Department of Environmental Conservation - Region 2 Office	Brooklyn Bridge Park, Gantry Plaza State Park, North 5 th St. Pier	5, 9	7	0	973	F
Nyack College	World's Fair Marina, Francis Lewis Park, Little Bay Park	2, 3	4	0	357	S, F, T
Randall's Island Park Alliance	Randall's Island Park	4b, 5	7	7	1,292	S, F, T

the Harlem River. It was bordered by the Willis Avenue Bridge (north border), the eastern aspect of RFK Bridge (eastern border), and the Wards Island Bridge (southern border); Zone 5, studied by RIPA and CPFCC, included Mill Rock and was a convergence point for the Harlem River and water from Hell Gate. Its boundaries were between the Wards Island Bridge (northwestern border) and the RFK Bridge’s southern aspect (northeastern border) to the Ed Koch Queensboro Bridge (southern border). It included Hallet’s Cove and waters surrounding Roosevelt Island north of the Ed Koch Queensboro Bridge; Zone 6, studied by NYSOPRHP and NYSDEC, was between the Ed Koch Queensboro Bridge and Queens Midtown Tunnel and included U Thant Island and the southern tip of Roosevelt Island; Zone 7, studied by LESEC and NYSDEC, was between the Queens Midtown Tunnel and Williamsburg Bridge. It included the widest part of the southern half of the East River strait, and it also had access to Newtown Creek; Zone 8, studied by LESEC, was between the Williamsburg Bridge and Manhattan Bridge and included the Brooklyn Navy Yard; Zone 9, studied by BBP and NYSDEC, was between the Manhattan Bridge and Hugh L. Carey Tunnel, and these waters widened into the Upper Bay; Zone 10, studied by BPCA, was Upper New York Bay, limited to Robert F. Wagner Jr. Park of Battery Park and the water immediately surrounding Governor’s Island.

Materials and Methods

In 2019, ERIA collected marine faunal data from community science programs and the general public. Fish species were identified and measured in conjunction with ambient water quality conditions to create a season-long profile of fish distribution in the strait.



Figure 1. East River Ichthyological Alliance (ERIA) East River Zones of Study. Each zone was demarcated between commonly recognized city landmarks (e.g., bridges, tunnels). A detailed description of zones can be found in the main text. Illustration © Hannah Ahn.

Partners submitted all the observations to a common database (hereafter referred to as “East River Fish Database”) for record-keeping and analysis. Data were also contributed by recreational East River strait anglers, for-hire fishing operations, and users of iNaturalist.org. In addition to collecting data, fishing clinics at Brooklyn Bridge Park, Randall’s Island Park, and World’s Fair Marina were initiated in 2019 to highlight the underwater life and support fish enthusiasts of all ages.

Fish species diversity, capture method, and sampling effort were the focus of the present work. Collection methods consisted of netting via seine net, cast net, or dip net; angling during fishing clinics or recreationally; trapping; or personal observation. All seining and trapping data were acquired by an environmental education organization or academic institution. Seining employs a long, rectangular net dragged along a shoreline by at least 2 people (Říha et al. 2008). Depending on the organization, beach seine nets varied in size from 15 to 30 ft (457 to 914 cm), but all were ¼ inch (6.35 mm) mesh. Trapping involved the use of oyster mesh cages, Gee minnow traps, or crab traps. Angling involved hook-and-line bait fishing or lure fishing. Data submitted by recreational anglers required supplementation with photographs. Personal observations were made in the field only by ichthyologists.

During community science events, fish specimens were tallied and when possible, photographed. A variety of best practices were implemented to prevent recaptures during a collection period. During seining, fish were held temporarily until tallies were completed, but, if fish had to be released early on or in the interim, new tallies for the released species were not performed. In some instances, a single haul caught specific fish species (e.g., *Menidia menidia* Linnaeus [Atlantic Silverside], Atlantic Menhaden, *Fundulus heteroclitus* Linnaeus [Mummichog]) that were too-many-to-count (TMTC). In these cases, fish could not be temporarily held, because of mortality risk, and were assigned an upper limit estimate of 250 individuals for tally purposes; these estimates of 250 individuals were consistently conservative based on photograph documentation, when available. For catch-and-release angling during fishing clinics, fish were measured and, when possible, photographed to confirm that the same individual was not recaptured. As needed, photographs were shared with experts in state agencies and academic institutions to confirm identification. Total length, in cm, was measured in the field for as many fish specimens as possible. Total length was measured in lieu of standard length for practical reasons (e.g., familiarity by anglers, experience of environmental educators). Specific attention was given to adult East River “sportfish”, which is a term for fish species sought by anglers because of their recreational importance (NYSDEC 2020d). These species have substantial economic value for New York State, and, thus, the occurrence of adult sportfish in the East River strait is highlighted (DiNapoli 2015, NYSDEC 2020e).

Catch-per-unit-effort (CPUE) is a concept used to standardize fish collection data (Maunder et al. 2006). Effort can be defined in a variety of ways, but determining an effort variable that was genuinely standard for the totality of collection methods employed in this work proved challenging. For example, during seining, the number of hauls per outing was recorded. For angling, the number of rods per outing was recorded whenever possible, but this variable was not always convenient to record for all fishing clinics. In contrast, recording effort by recreational anglers was not feasible as angler experience and fishing duration varied widely or simply could not be obtained. Similarly, fishing with traps, such as Gee minnow traps and oyster cages, varied greatly in terms of time between deployment and retrieval. Therefore, for analysis purposes, our measure of effort was “session”, defined as an independent outing in which fish data were collected, via program (e.g., fish count, fishing clinic) or recreationally (e.g., fishing trip). We acknowledge that “session”

is an imperfect measure that included various durations and methodologies, but it was the only measure of collective effort that could be derived in the present work. The value of a proxy for effort, over the lack thereof, is that it can provide a critical first exploration that can reveal the necessity for and nature of more appropriate finer-scaled effort variables for future community science projects. The flexibility afforded by “sessions” served an important purpose when working within different community group needs and still captured important species’ abundance and presence information that would have otherwise gone uncollected. Every “session” had to be reasonably limited to a specific locale (e.g., Brooklyn Bridge Park Pier 5, Francis Lewis Park), involve a continuous collection attempt from beginning to end of a single session, and have a duration that was no more than 5 h. Most environmental education programs were 1.5 to 3 h, but recreational angling “sessions” were more variable. Different collection methods employed simultaneously at the same site were recorded as independent “sessions”. For example, if seining and angling occurred at the same time and site, the seining catch was counted as a separate “session” from the angling catch.

Two species diversity indices were used to explore fish diversity across zones: the Shannon–Wiener Index (H) (Shannon and Weaver 1949) and Simpson’s Index of Diversity (1-D) (Simpson 1949). Species diversity indices treat each species as an independent observation and consider species richness (number of species) and species evenness (relative abundance or number of individuals of each species that make up the species richness in an area). We acknowledge that certain assumptions of these indices may not have been met in the present work (e.g., random sampling, standardized methods), and, thus, our calculation of indices should be interpreted cautiously when compared across zones. Each index still provides critical preliminary baseline data upon which to focus future community science data collection efforts. H is the most popular species diversity index used by ecologists and ranges from 0 to ~3.5, with higher values indicating greater diversity. H incorporates a greater emphasis on rare species. The 1-D index ranges from 0, when 1 species dominates the community entirely, to 1, when there is high evenness or all species are equally abundant, which is interpreted as high diversity. In contrast to H, 1-D is less sensitive to rare species because it gives more weight to the most abundant species. The software program PAST (Paleontological Statistics, version 3.26; Hammer et al. 2001) was used to calculate diversity indices. PAST also computed 95% confidence intervals for indices using a bootstrap procedure, and non-overlapping confidence intervals among zones could be interpreted as differing index values. Finally, rank abundance curves (Whittaker 1965) were plotted for each zone, with species rank abundance on the x-axis and proportional abundance on the y-axis. Tropical strays were omitted from diversity calculations and rank abundance plots because they did not represent East River native fauna.

All fish caught during programs were gently handled and safely released. When fish needed to be kept briefly for identification, they were placed in containers with sufficient water and aerators, as available. Every precaution was taken to prevent or minimize injury, in accordance with guidelines outlined by state or park permits. Best practices to minimize fish mortality and injury were shared and developed among environmental education organizations. One of the benefits of public angling programs is the education of a significant number of anglers, students, and other community members toward respectful fish handling and release. Jenkins et al. (2014) provides detailed guidance for handling fishes in research. Recreational anglers implemented similar guidelines. Any fish kept by recreational anglers were kept in accordance with NYSDEC Recreational Saltwater Fishing Regulations (NYSDEC 2020d).

Results

2019 East River Fish Data by Zone

Data quality, aspects of which include data accuracy, reliability, and methodology, is a substantial concern for community science projects (Aceves-Bueno et al. 2017). To control data accuracy, all data collected during community science events (e.g., species identification, abundance) were overseen on-site by trained ecologists, ichthyologists, or environmental educators with follow-up verification using photographs, as needed. All data collected by anglers were validated with photographs. In 2019, ERIA recorded 47 fish species, encompassing a total of 9279 individual fish. Hereafter, the designation “*n*” will be used to refer to sample size of individuals, while “*a*” will be used to refer to number of species. Table 2 summarizes species richness, number of individuals caught, and number of sessions’ data for each zone; “session” was a proxy for effort. The vast majority of individual fish (81%, *n* = 7,525) were recorded from programs by environmental education organizations (e.g., seining, fishing clinics). The remaining records were from recreational activities (e.g., angling).

Standardization of East River Data through a Proxy for Effort

Catch standardized by a proxy for effort was explored across zones for total number of individuals caught and species richness. Effort was defined as “session”, or an outing when fish data were acquired, via a program or recreationally, on a given day. The number of sessions varied widely across zones. Zones 3 and 9 were surveyed with the most sessions, and the greatest species richness was recorded in zones 9 (*a* = 29), 3 (*a* = 24), and 4b (*a* = 21). Zones 1, 4a, and 7 were least studied, and future data collection efforts should be focused on potential contributions from these sites.

Total number of individual fish caught and species richness were explored via regression analysis. Each variable was natural log-transformed to align with statistical assumptions (e.g., normal distribution, homoscedasticity). LN-transformed number of individuals caught per zone on LN-transformed number of sessions (effort) per zone was statistically

Table 2. Complete Catch Data by Zone as Contributed by Education Organizations and Recreational Anglers. This table combines data from educational organizations and recreational anglers. Species richness is total number of species per zone, excluding tropical strays shown in parentheses. Session was number of events or outings. Methods of collection were seining (S), angling (A, pooled data from fishing clinics [referred to as F in Table 1] and recreational angling), trapping (T), cast-netting (C), dipnetting (D), or observation (O).

Zone	Richness	No. Individuals Caught	Sessions	Method
1	7	100	2	S, A, D
2	19	2,332	24	S, A, C
3	22 (2)	951	49	A, T, C, D, O
4a	2	2	2	A
4b	20	2,462	20	S, A, T
5	16	495	19	S, A
6	10	72	21	A, T
7	3	15	3	A
8	5 (1)	13	8	A, T
9	29	2,617	31	S, A, T
10	13	220	21	A

significant ($F_{1,7} = 17.7, P < 0.05$). Likewise, LN-transformed species richness per zone on LN-transformed number of sessions per zone was statistically significant ($F_{1,7} = 102.2, P < 0.05$). Thus, unsurprisingly, an increased number of sessions was associated with more species caught and with greater number of individual fish caught (total abundance) across zones. To standardize for effort at each zone, residuals were acquired for both species richness per zone and number of individual fish caught per zone from the previous regressions. Correlation analysis between the 2 sets of residuals was statistically significant ($t_s = 5.2102, df = 9, P < 0.05$) (Fig. 2). Ratios were not used for standardization because of their numerous complications in statistical analyses (Sokal and Rohlf 2011, Zar 2010). In summary, independent of number of sessions, a higher number of individuals caught was associated with more species discovered, across zones.

East River Fish Species Richness Covariates

Species richness could be influenced by fish catching effort or total number of individual fish caught. Therefore, species richness values for each zone were plotted separately with number of individual fish caught (Fig. 3A) and with number of sessions (Fig. 3B). For species richness on number of individuals caught, a second-order polynomial regression was a better predictor of the data ($F_{2,8} = 20.41, P = 0.0007$) than linear regression ($F_{1,9} = 19.76, P = 0.0016$) (Fig. 3A). In contrast, for species richness on number of sessions,

Figure 2. Number of Individual Fish Caught by Species Richness. Each axis represents residuals (i.e., x-axis from zone species richness on sessions, y-axis from zone number of individuals caught on sessions), which represent variables standardized by “session,” a simplistic proxy for effort.

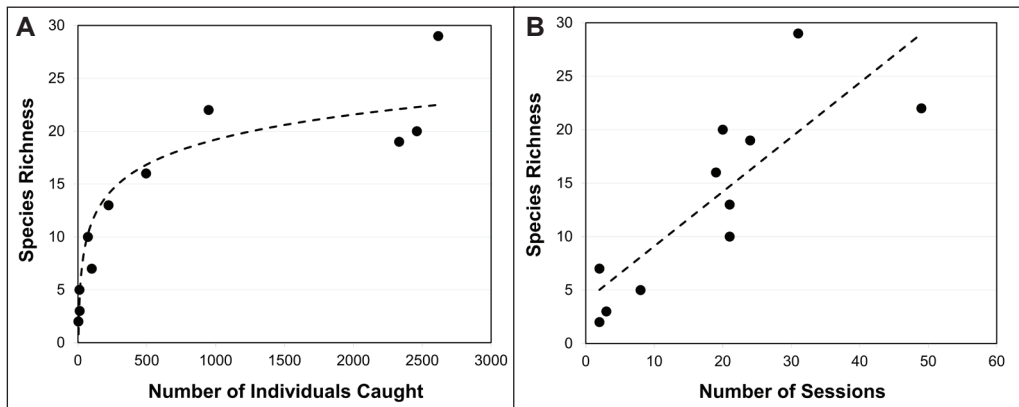
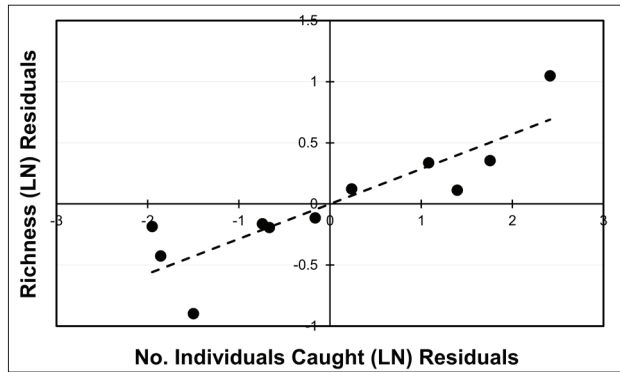


Figure 3. (A) Fish Species Richness by Number of Individuals Caught. Species richness of each zone was plotted with their corresponding total number of individuals caught. (B) Fish Species Richness by Number of Sessions. Species richness of each zone was plotted with their corresponding total number of “sessions,” a simplistic proxy for effort.

a linear regression ($F_{1,9} = 25.44$, $P = 0.0007$, Fig. 3B) was a better fit than second-order polynomial regression ($F_{2,8} = 15.75$, $P = 0.0017$).

Species Diversity across Zones

Table 3 and Figure 4 summarize calculations for the Shannon–Wiener Index (H) (Fig. 4A) and Simpson’s Index of Diversity (1-D) (Fig. 4B). In descending order, zones 9, 3, 4b, and 2 had the highest species richness, but they did not necessarily have the highest relative ranks for the indices. Based on non-overlapping confidence intervals, zones 3 and 6 had the highest values for each diversity index. Zone 4b showed inconsistency between diversity indices, likely due to sample error from being the least sampled. While the patterns of H and 1-D across zones were comparable, more accurate species richness and diversity measurements for East River strait zones will require more standardized approaches to citizen science data collection (e.g., quadrats, transects).

Rank abundance curves of zones were plotted (Fig. 5), but substantial differences among gradients (slopes) of the curves were apparent only up to the seventh species rank. Thus, subsequent species ranks were omitted from the figure for convenience of visualization. Zones 2, 5, 9, and 10 had steep gradients, indicating low evenness, and zones 3, 6, and 8 had relatively shallower gradients, indicating higher evenness or similar abundances across different species. Zones 1, 4b, and 7 had intermediate gradients.

2019 East River Fish Species Inventory

Forty-seven fish species were recorded in the East River strait in 2019 (Table 4), and all were previously observed in the Hudson River Estuary. Forty-four of these species were considered native to the East River strait, based on classifications in Hardy (1978), Murdy et al. (1997), and Nelson (2006). The remaining 3 species were classified as tropical strays, which we defined as non-native fishes with the following characteristics: born in southern tropical waters, swept into the East River strait via the Gulf Stream (no migration), not expected to survive during colder months as water temperatures fall, and very rare as adults in East River strait waters.

The order of species abundance was 66.95% Atlantic Silverside ($n = 6,212$), followed by 8.71% *Fundulus* spp. (local killifish species, $n = 808$) and 6.85% Atlantic Menhaden ($n = 636$). This result was not surprising as all 3 groups of fish are ecologically classified as forage fish and, thus, occupy lower trophic levels (Murdy et al. 1997). In addition to their expected higher abundance, they tend to occupy habitats that are especially accessible by seining. The next most abundant species were as follows: 2.68% *Morone saxatilis* Walbaum (Striped Bass), 2.20% *Centropristis striata* Linnaeus (Black Sea Bass), 2.14% *Pomatomus saltatrix* Linnaeus (Bluefish), 1.71% *Microgadus tomcod* Walbaum (Atlantic Tomcod), and 1.16% *Bairdiella chrysoura* Lacepède (Silver Perch). All remaining fish ($a = 36$ species) had a relative abundance of less than 1 percent.

Species richness was analyzed by capture method: angling, seining, cast net, dip net, trapping, or personal observation. Figure 6 summarizes species by capture method, where the capture of a fish species by a specific method was treated as presence/absence data, and, thus, species abundance was not considered. For species that were caught using multiple methods, the presence of a capture by each method was treated as a separate individual observation. For example, Black Sea Bass were caught via angling and trapping, and each method was counted as its own individual observation. A total of 83 capture method observations were recorded. Twenty-four of the 47 species (51%) were collected using only 1 collection method. In contrast, some species, such as Atlantic Silverside, were collected

Table 3. Diversity indices across zones. Shannon–Wiener Index (H), Simpson’s Index of Diversity (1-D), and species richness (Richness) values shown for East River strait zones. Ninety-five percent confidence intervals (CI) for indices were based on the bootstrap procedure, as implemented by PAST (Paleontological Statistics, version 3.26; Hammer et al. 2001).

Zone	Richness	Shannon (H)		95% CI		Simpson (1-D)		95% CI	
		Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower
1	7	1.006	1.204	0.959	0.566	0.624	0.545		
2	19	0.931	0.991	0.872	0.359	0.384	0.335		
3	22	1.740	1.820	1.678	0.750	0.767	0.734		
4a	2	0.637	0.637	0.000	0.444	0.444	0.000		
4b	20	1.312	1.367	1.263	0.577	0.597	0.559		
5	16	0.786	0.923	0.681	0.292	0.351	0.249		
6	10	1.580	1.831	1.445	0.703	0.788	0.633		
7	3	0.790	1.012	0.271	0.462	0.615	0.142		
8	5	1.414	1.547	1.034	0.711	0.777	0.546		
9	29	0.980	1.048	0.923	0.341	0.366	0.319		
10	13	1.373	1.556	1.226	0.565	0.640	0.494		

Figure 4. A. Shannon-Weiner (H) Diversity Index and Species Richness. B. Simpson's Index of Diversity (1-D) and Species Richness. X-axis is East River strait zone, and species richness is depicted as bars. Index values are plotted on y-axis, and 95% confidence intervals for indices based on bootstrap procedure as implemented by PAST version 3.26 (Hammer et al. 2001) are dotted lines.

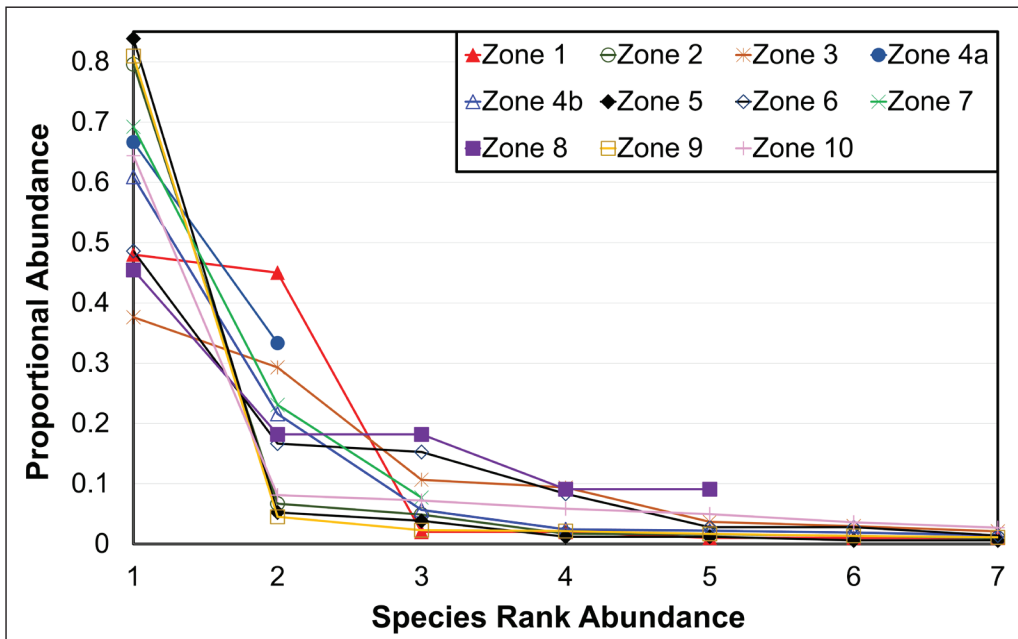
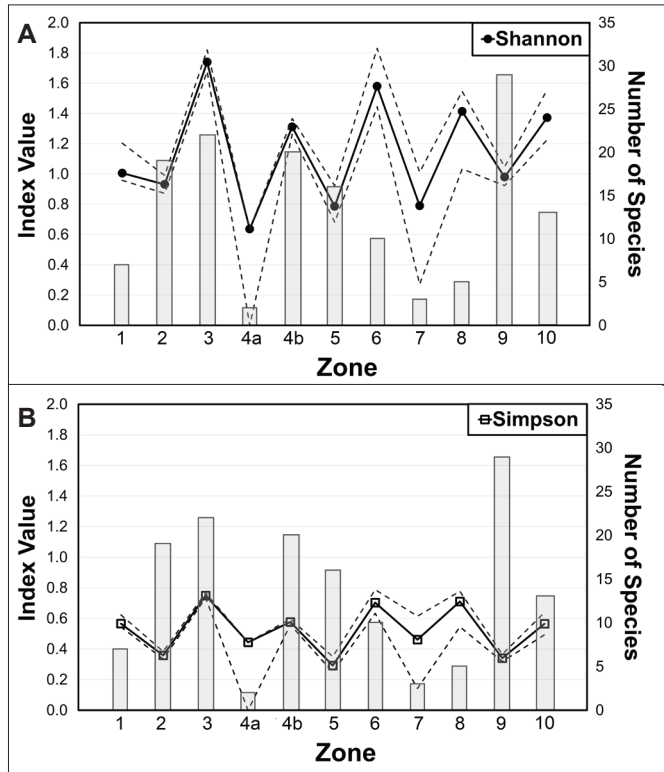


Figure 5. Rank Abundance Curves by Zone. Rank abundance curves for all zones are shown, up to the seventh species rank; subsequent species ranks are not displayed for curves because their slopes beyond this rank did not differ substantially. Species rank abundance is on the x-axis, and proportional abundance is on the y-axis.

Table 4. 2019 East River Fish Species Inventory. Common name, scientific name, and species abundance (n) are shown. The geographic range column indicates if species are considered native or tropical stray of the East River. Methods of collection were seining (S), angling (A), includes fishing clinics and recreational angling), trapping (T), cast-netting (C), dipnetting (D), or observation (O).

Common Name	Scientific Name	Range	n	Method
Alewife	<i>Alosa pseudoharengus</i>	native	2	S
Anchovy, Bay	<i>Anchoa mitchilli</i>	native	86	S
Anchovy, Striped	<i>Anchoa hepsetus</i>	native	27	S
Bass, Striped	<i>Morone saxatilis</i>	native	249	A, S, C, O
Blenny, Feather	<i>Hypsoblennius hentz</i>	native	1	T
Bluefish	<i>Pomatomus saltatrix</i>	native	199	A, S
Cunner (Bergall)	<i>Tautoglabrus adspersus</i>	native	32	A, S, T
Dogfish, Smooth	<i>Mustelus canis</i>	native	10	A
Eel, American	<i>Anguilla rostrata</i>	native	13	A, S
Eel, Conger	<i>Conger oceanicus</i>	native	1	A
Flounder, Summer	<i>Paralichthys dentatus</i>	native	32	A, S, T
Flounder, Windowpane	<i>Scophthalmus aquosus</i>	native	1	T
Flounder, Winter	<i>Pseudopleuronectes americanus</i>	native	30	S, T
Goby, Naked	<i>Gobiosoma bosc</i>	native	7	S, T
Goby, Seaboard	<i>Gobiosoma ginsburgi</i>	native	2	T
Hake, Spotted	<i>Urophycis regia</i>	native	5	A, T
Herring, Atlantic	<i>Clupea harengus</i>	native	1	S
Herring, Blueback	<i>Alosa aestivalis</i>	native	1	S
Hogchoker	<i>Trinectes maculatus</i>	native	2	T
Killifish, Striped	<i>Fundulus majalis</i>	native	176	S
Kingfish, Northern	<i>Menticirrhus saxatilis</i>	native	33	S
Menhaden, Atlantic	<i>Brevoortia tyrannus</i>	native	636	A, S, C, D
Mullet, White	<i>Mugil curema</i>	native	49	S

Table 4. Continued.

Common Name	Scientific Name	Range	n	Method
Mummichog	<i>Fundulus heteroclitus</i>	native	632	S, T
Needlefish, Atlantic	<i>Strongylura marina</i>	native	5	S, O
Perch, Silver	<i>Bairdiella chrysoura</i>	native	107	T, S
Perch, White	<i>Morone americana</i>	native	34	A, T, S
Pipefish, Northern	<i>Syngnathus fuscus</i>	native	67	S, C
Puffer, Northern	<i>Sphoeroides maculatus</i>	native	7	A, S
Sculpin, Grubby	<i>Myoxocephalus aeneus</i>	native	9	S, T
Scup (Porgy)	<i>Stenotomus chrysops</i>	native	85	A, S
Sea Bass, Black	<i>Centropristis striata</i>	native	204	A, T
Sea Robin, Northern	<i>Prionotus carolinus</i>	native	1	T
Sea Robin, Striped	<i>Prionotus evolans</i>	native	25	A, S
Shad, Gizzard	<i>Dorosoma cepedianum</i>	native	1	C
Shad, Hickory	<i>Alosa mediocris</i>	native	1	A
Silverside, Atlantic	<i>Menidia menidia</i>	native	6,212	A, S, C, D, O
Skilleffish	<i>Gobiosox strumosus</i>	native	9	S
Spot	<i>Leiostomus xanthurus</i>	native	15	S
Stickleback, Fourspine	<i>Apeltes quadracus</i>	native	4	T
Tautog (Blackfish)	<i>Tautoga onitis</i>	native	36	A, S, T
Toadfish, Oyster	<i>Opsanus tau</i>	native	67	A, S, T
Tomcod, Atlantic	<i>Microgadus tomcod</i>	native	159	S, T, C
Triggerfish, Gray	<i>Balistes capricus</i>	native	1	T
Butterflyfish, Spotfin	<i>Chaetodon ocellatus</i>	tropical stray	1	T
Cobia	<i>Rachycentron canadum</i>	tropical stray	1	O
Snapper, Gray	<i>Lutjanus griseus</i>	tropical stray	1	T

using 5 out of the 6 available methods. Of the 47 species from 2019 documented in the East River strait, seining accounted for the capture of most species (37.35%), followed by trapping (26.51%) and angling (21.69%) (Fig. 6).

2019 Sportfishes of the East River Strait

Sportfish are fish species that are targeted by anglers for their recreational value (NYS-DEC 2020a). In the East River strait, marine sportfish species are generally large predatory species that occur as adults throughout the strait more ubiquitously than other species. Based on present data, the following species were identified as the most wide-ranging sportfishes of the East River strait in 2019, using a criterion of occurrence as adults in at least 6 of 11 zones: Striped Bass (10/11 zones), *Opsanus tau* Linnaeus (Oyster Toadfish, 8/11 zones), Bluefish (7/11 zones), *Paralichthys dentatus* Linnaeus (Summer Flounder; 7/11 zones), *Stenotomus chrysops* Linnaeus (Scup; 7/11 zones), *Tautoga onitis* Linnaeus (Tautog; 7/11 zones), and American Eel (6/11 zones).

Expanding East River Fish Species Inventory (2009–Present)

Records and photographs of fish species documented before 2019 were obtained from Battery Park City Authority (2015–present), Brooklyn Bridge Park (records spanning 2009–present), City Parks Foundation (2013–present), Nyack College (2017–present), and Randall’s Island Park Alliance (2015–present). Several fish species absent in 2019 but previously observed in the East River strait are listed in Table 5. Species redundant with those listed in the 2019 East River fish species inventory were excluded. Putting all data together, since 2009, the East River strait has confirmed records for 58 fish species, and 9 of these species were tropical strays. The remaining non-native species, Western Mosquitofish (*Gambusia affinis* Baird and Girard), native to the Mississippi Valley, is a freshwater and brackish water species that can be classified as a non-native introduction, usually introduced to freshwater areas to control mosquitoes (Nico et al. 2020b). *G. affinis* has been classified as a non-native species in the Hudson River Estuary by Mills et al. (1996). Taking the data together, and excluding tropical strays and Western Mosquitofish, it is striking that the present 2019 survey recorded 44 of 48 (92%) native estuarine species documented for the East River strait since 2009.

Figure 6. Pie Diagram of Percentage of Fish Species Caught by Collection Method. Each fish species caught was treated as an independent event, and abundance per species was excluded. If a fish species was caught using multiple methods, each occurrence was counted independently. This diagram summarizes a total of 83 observations with many species caught using more than one method.

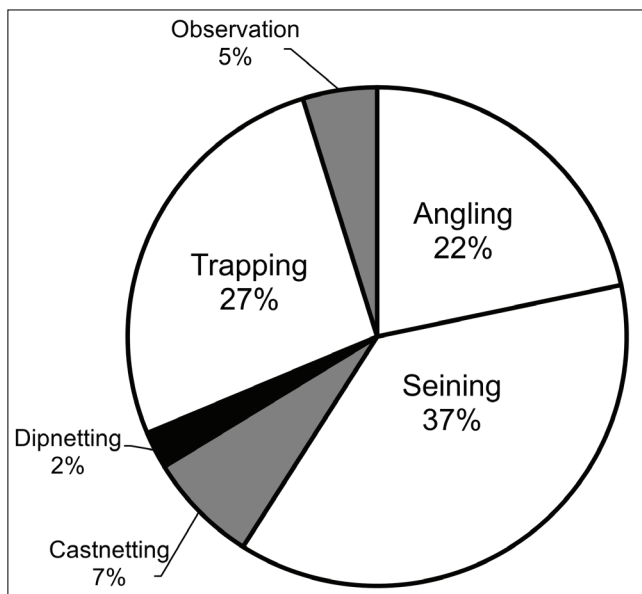


Table 5. East River Fish Species Absent in 2019. The geographic range column indicates if species are considered (non)native or tropical stray of the East River. Methods of collection were seining (S) or recreational angling (A).

Common Name	Scientific Name	Location	Range	n	Year Found	Method
Pollock	<i>Pollachius virens</i>	Brooklyn Bridge Park	native	1	2018	S
Seahorse, Lined	<i>Hippocampus erectus</i>	Brooklyn Bridge Park; Little Bay	native	3	2009, 2014, 2015;	S
Shad, American	<i>Alosa sapidissima</i>	Brooklyn Bridge Park	native	1	2017	S
Stargazer, Northern	<i>Astroscopus guttatus</i>	Brooklyn Bridge Park	native	1	2012	S
Mosquitofish, Western	<i>Gambusia affinis</i>	Brooklyn Bridge Park	nonnative, fresh-water	1	2016	S
Burrfish, Striped	<i>Chilomycterus schoepfi</i>	Brooklyn Bridge Park	tropical stray	1	2018	S
Cornetfish, Bluespotted	<i>Fistularia commersonii</i>	Brooklyn Bridge Park	tropical stray	1	2015	S
Drum, Black	<i>Pogonias cromis</i>	Robert F. Wagner Jr. Park	tropical stray	1	2017	A
Jack, Crevalle	<i>Caranx hippos</i>	Brooklyn Bridge Park	tropical stray	1	2015	S
Rudderfish, Banded	<i>Seriola zonata</i>	Brooklyn Bridge Park	tropical stray	7	2018	A
Sennet, Northern	<i>Sphyraena borealis</i>	Brooklyn Bridge Park	tropical stray	1	2010	S

Discussion

New York City's East River is one of the most famous and heavily utilized tidal straits in the world. In 2019, environmental educators, researchers, fishing captains, and recreational anglers joined to form a network to survey East River fish fauna in relation to species composition, species richness, abundance, and diversity. Data were collected via public and non-public programs (e.g., fishing clinic, seining) and recreational activity (e.g., shore fishing, boat fishing). Data contributed by environmental educators derived from 9 organizations (Table 1). The emergence of ERIA builds on a notable tradition of data gathering partnerships focused more broadly on the Hudson River (see Nolan et al. 2013) and local community science symposia, such as the Youth Educational Seining symposium (St. Francis College, Brooklyn, NY), which for years have brought together local organizations and scientists to discuss their programs and the potential for collaborations.

To permit analyses of species diversity within and among publicly utilized areas of the East River strait, the strait was divided into 11 zones based on the locations of environmental education organization study sites, human-made physical landmarks (e.g., bridges, tunnels), and public access (e.g., public park). In general, almost all zones had at least 1 organization collecting data at somewhat regular time intervals throughout 2019 (Table 1). Survey efforts in the present work considerably spanned the geographic extent of the East River strait, excepting zone 4a. The dataset analyzed in this work represents the efforts of over 2300 public participants (Table 1) and remains a uniquely comprehensive season-long profile that, for some sites, included weekly collection records.

Estimating the number of species in a geographic area is usually accomplished by plotting a species accumulation curve, which typically exhibits a curvilinear relationship between species richness and an effort or sample size variable. While our community science efforts in 2019 did not intentionally seek to describe a species accumulation curve for the East River strait, Figures 3A and 3B serve as preliminary data for potential such analyses. Species accumulation curves are typically calculated from multiple random samples of subareas of the same localized geographic area (Gotelli and Colwell 2001). Figure 3A did show a curvilinear relationship, but interpretation of this result is complicated because each zone had pooled data from a variety of collection methods. Zones, by definition, were also relatively large non-overlapping areas that covered varying ranges of depth, tide, and sediment qualities that may not vary randomly. Thus, it remains unclear if the East River strait can be considered a single geographic area. Furthermore, many fish species in this study are pelagic and inevitably move throughout the system. Further research is needed regarding the detailed characterization of ecological habitats and the extent of mobility of species across zones.

The overall result of Figure 3A does, however, suggest possible next steps for East River strait research that could be adapted to community science, such as: (i) Outlining and mapping reliable physical and ecological characteristics and boundaries for a study site will be critical for comparability of datasets within and across sites. Understanding each site more fully, along with the broader zone to which it belongs, could provide insights into the appropriate scale for reliable replication. Sites could be defined by spatial parameters (e.g., area covered; relative occurrence of specific habitats, like marshes, gradual slopes, or rip-rap, Valenti et al. 2017) or temporal parameters (e.g., the average speed of currents, frequency of natural and anthropogenic disturbances) to identify and, thus, eliminate sampling biases. (ii) To improve data quality, validation studies performed exclusively by professionals could be done side-by-side with community science events to evaluate criteria for "adequate" sampling of a site. For example, for seining, a team of researchers could first acquire baseline biodiversity data using standard ecological meth-

ods for a site during days leading up to a public community science event. On the event day, data could be collected as usual during the program through public participants, and, afterward, results obtained by biologists and by public participants can be compared to validate methods (e.g., seining technique), which may identify and lead to the improvement of least effective approaches or tools. As a second example, each environmental organization could design programs with the specific goal of plotting species accumulation curves for their site; these data could be collected separately by biologists and by public participants and then compared within and among sites. A final example would be to investigate if species richness changes throughout the year can be monitored by way of species accumulation curves from different meaningful time points (e.g., season, water temperature shifts). (iii) While equal sample size and effort across study sites will be impossible for the entire East River strait, continued standardizing of data collection methods (e.g., seining protocols, fishing rigs and baits, choice of water quality tests) will inevitably improve data quality. Thus, while the interpretation of community science data has inherent challenges, data quality can be improved, which, in turn, will improve what we can or cannot say with the data available.

In contrast to Figure 3A, the plot of species richness and total number of “sessions” (Fig. 3B) did not yield a plateau at higher values of “sessions”. These results can be interpreted in 2 ways. If “sessions” accurately reflected effort, then these results would suggest that the East River strait has been under-sampled, as indicated by the lack of a plateau at higher “sessions” values. On the other hand, the lack of a fit to a curvilinear regression may indicate that “sessions”, an admittedly non-standardized metric, is an inaccurate measure of effort. At the present time, we cannot distinguish between explanations. However, the use of “sessions” as effort was still sufficient to detect an association with species richness as well as with number of individuals caught. Upon controlling for “sessions”, more species were found when more individual fish were caught (Fig. 2). Despite the lack of available alternatives for generalized effort, “sessions” still provided an important first investigation that emphasizes the need for more effective solutions to measuring effort across method types. We do not recommend relying exclusively on “sessions” in community science endeavors. Instead, future work should focus on identifying and analyzing other proxies for effort, if possible, such as sample area size, precise hours of investigation, number of hauls during seining, or number of rods used during fishing. The relationship between species richness and such variables could then be explored to determine the best proxy of effort for specific and general contexts.

Our 2019 survey identified 47 fish species, 3 of which were classified as tropical strays (Table 4). The present work illustrates the importance of documenting sampling method. Of the 47 species from 2019 documented in the East River strait, seining accounted for the capture of most species (37.35%), followed by trapping (26.51%) and angling (21.69%). Of the 47 species documented, 51% of fish species were caught only using 1 sampling method: 3 species were caught only by angling, 9 species were caught only by trapping, 10 species were caught using a seine net, and the remainder were from cast netting or personal observation. Seining is a particularly useful method because it is not particularly selective of species caught. It is also best employed in shallow habitats with low energy, which attract smaller fish species and their predators. Additionally, seining is a visually understandable and exciting activity for public audiences, which immediately sparks the scientific curiosity of “What’s in the net?” across all languages and social demographics. In 2019, seining generally caught small fish or young-of-the-year (YOY) fish, while angling was especially well suited to catching moderate- to large-sized predatory fish, and trapping accounted for unique catches. The multiple method approach also made participation equitable across waterfront types, with

seining ideal for gradual shallows, and angling and trapping employed from docks, piers, and high energy waterfronts. While each method has its advantages and disadvantages, if only 1 standard sampling method was implemented, many species would have never been caught, substantially impacting the representation of East River fish diversity in 2019.

The 2019 fish species inventory was expanded to include species absent in 2019, but that were recently observed in the East River strait. Between 2009 and 2018, records from Battery Park City Authority, Brooklyn Bridge Park Conservancy, and Nyack College documented an additional 11 species, each with photograph documentation, and 6 of these species can be classified as tropical strays (Table 5). Thus, including these records dating back to 2009, the ERIA East River fish inventory was expanded to 58 species, 9 of which were tropical strays. The Western Mosquitofish, a freshwater species introduced into surrounding freshwater waterbodies for mosquito control, was a notable outlier observed in zone 9 during 2016. The only *Gambusia* species with a native range close to the East River strait is *Gambusia holbrooki* Girard (Eastern Mosquitofish), which occurs from Alabama to Delaware (Arndt 2004, Nico et al. 2020a), and, although this species has been anecdotally reported in New Jersey, it has not been confirmed so far north (Arndt 2004). There are many other local fish species that are commonly observed in neighboring waters, such as the Hudson River and Atlantic Ocean, but that were not documented in this work in the East River strait since 2009. Continued work will focus on expanding the inventory with photographic documentation.

In New York City, sportfish species are listed in recreational fishing regulations every season (NYSDEC 2020d), and New York State's sportfish fisheries are of great economic and social importance. In 2011, consumer expenditure on hunting and fishing in New York State amassed \$5 billion, and, in 2012 to 2013, New York State revenue from fishing and hunting licenses and permits amounted to \$50 million (DiNapoli 2015). In the East River strait, marine sportfish species are generally large predatory species as adults. In 2019, Striped Bass, Oyster Toadfish, Bluefish, Summer Flounder, Scup, Tautog, and American Eel were the most wide-ranging sportfishes of the East River strait. It is not unreasonable to speculate that each of these species resides in the East River strait as adults in all zones studied, because of their wide-ranging occurrence. New York fish conservation efforts are focused on sportfishes, as evident in their regulated size and creel limits. Sportfishes act as umbrella species (Frankel and Soulé 1981, Roberge and Angelstam 2004), which, when protected, will inevitably benefit a substantial number of other species across multiple trophic levels.

Regarding tropical strays, while they are fascinating for having traveled long distances via the Gulf Stream, they are unpredictable temporary visitors and do not represent the native fishes of the East River strait. All strays were YOY except for 1 notable exception, a sizeable Black Drum (*Pogonias cromis* Linnaeus) specimen conservatively weighing more than 10 kg (22.05 lbs), caught in Battery Park in 2017. A substantial proportion (15.52%) of fish species recorded between 2009 and 2019 were classified as tropical strays. The ecological role that these fish play in the East River strait remains unknown. Strays are rare, but they are also understudied in the strait. While it is reasonable to assume that most become prey, other consequences of their arrival are plausible. For example, tropical strays may outcompete YOY native species, introduce pathogens, or consume a variety of native prey. In light of climate change, the roles of these fish may become more consequential because of habitat shift (Morley et al. 2018, Morson et al. 2019). However, as of yet, no evidence suggests significant consequences brought by tropical strays into the East River strait. Community science fish survey programs are more frequent than surveys conducted by state agencies and academic institutions, and, thus, can supplement and contribute to knowledge of the status of tropical strays and overall native fish populations.

Analysis of fish life stage data will be the focus of future work. While the East River is a strait with strong tidal currents, it is connected to 3 substantial bodies of water, the Atlantic Ocean, Hudson River, and Western Long Island Sound, all of which likely provide breeding grounds or nurseries for fish assemblages described here as native to the strait. Total length data could be used to determine fish life stages, such as YOY, larval, juvenile, or adult. Depending on the species, the term “YOY” and the other listed terms are not mutually exclusive. YOY individuals of any predatory species likely occupy realized niches similar to those occupied by forage fish, at least until predatory species outgrow them. The presence of larval fish may be particularly suggestive of which species are born in the East River strait. In 2019, larval specimens were collected for Atlantic Silverside, Atlantic Menhaden, Mummichog, and *Fundulus majalis* Walbaum (Striped Killifish). YOY specimens may or may not have been born in the East River strait. YOY were found for all except only a handful of species (i.e., *Mustelus canis* Mitchell [Smooth Dogfish], *Balistes capriscus* Gmelin [Gray Triggerfish], *Strongylura marina* Walbaum [Atlantic Needlefish], *Gobiesox strumosus* Cope [Skilletfish], *Conger oceanicus* Mitchell [Conger Eel]). Most documented East River fish species are probably using the strait as a nursery, but the total number of species that are born, grow into adults, and/or use these waters as breeding grounds remains uncertain.

Two popular species diversity indices were used to explore the 2019 East River strait fish dataset: the Shannon–Wiener Index (H) and Simpson’s Index of Diversity (1-D). Species diversity incorporates both species richness and species abundance, but the choice of index to measure this diversity is not straight forward (Chiarucci et al. 2011, Gotelli and Colwell 2011, Jost 2007, Magurran 2004, Margalef 1958). For example, despite its wide use, a given value of H can result from multiple possibilities, such as a simultaneous increase in evenness and richness or an increase in evenness while the richness remains relatively constant (or vice versa) (Loisea and Gaertner 2015). Justification for choosing these 2 indices was their widespread use in ecological research, ease of calculation, and pedagogical value in environmental education. Relative values for H and for 1-D were similar despite the variety of sampling methods employed and the different degrees of effort across sites.

The combination of diversity indices and rank abundance curves revealed that zones 3, 4b, 6, and 8 had high diversity and high evenness, zone 10 had high diversity but low evenness, and zones 2 and 9 had high richness but low diversity and evenness. Zone 9, which was the most speciose, had low scores for both H and 1-D and a steep rank abundance curve, indicating low evenness. In fact, 81% (2118 of 2617) of zone 9’s total catch was Atlantic Silverside, a species almost exclusively caught via seining. No seining occurred in zones 3, 4b, 6, 8, and 10. Zone 3 included roughly equivalent contributions from trapping, recreational angling, and fishing clinics, and data from zones 4b, 6, 8, and 10 were mostly from fishing clinics and recreational angling with occasional trapping. Zone 9 included seining, fishing clinics, trapping, and recreational angling. Zone 2 included mostly seining and some recreational angling. Finally, zone 10 had exclusively fishing clinics and recreational angling. Except for zone 10, our data generally suggests that seining is associated with lower evenness, or alternatively, angling is associated with higher evenness. However, without standardized collection methods, understanding the degree to which East River fish diversity is similar or different across zones still remains a moving target. Future work will explore species diversity and underlying species composition across the East River strait with specific focus on improving data quality.

Although the East River strait zones in this work were not initially intended to be ecologically meaningful or distinct, it would still be possible, if standard methods were employed, to explore whether 1 or more zones could be treated as a representative sub-

sample of the East River strait overall. For example, if sites were alike, local species diversity (alpha diversity) of each zone would be similar and species composition of fish assemblages across zones (beta diversity) would not change significantly. More broadly, biological diversity can also be analyzed beyond general species diversity, such as via functional diversity or evolutionary (phylogenetic) diversity (Gotelli and Colwell 2011, Magurran 2004). Functional diversity indices account for the role that species have in an ecosystem (e.g., guild, functional group), and these indices take into consideration the differences among species in relation to functional variables (Mason et al. 2003; Mouillot et al. 2005; Petchey and Gaston 2002, 2006; Stuart-Smith et al. 2013; Villéger et al. 2010). For example, Atlantic Menhaden, Mummichog, and Striped Killifish are all forage fish as adults, and these species have also been identified as indicator species (but see Siddig et al. 2016). In contrast, Striped Bass, Bluefish, and Summer Flounder are predators as adults and have high recreational value as sportfishes. Evolutionary (phylogenetic) indices account for the phylogenetic relationships among the species in a community (Clarke and Warwick 1998, 2001; Modica et al. 2011; Plazzi et al. 2010; Warwick and Clarke 1995). This approach may also be useful when a species cannot be identified to species level but other taxonomic information, such as genus or family, is available.

This work extends the scientific contributions of community programs in general. Fish community science data have the potential to highlight critical ecological relationships among other organisms in the East River strait. Collaboration across different community science groups may lead to greater understanding of ecosystems and success with restoration of ecological integrity. For example, long-term historical changes in fish abundance and distribution are associated with piscivorous bird abundance (Viverette et al. 2007). Thus, comparing avian, fish, and invertebrate community science data may provide insights into Ardeidae (heron) occurrence and foraging behavior (Post 2008), which may also enhance data accuracy in avian community science reporting (Aceves-Bueno et al. 2017). Community science also has the potential to fill in critical data gaps in fish demography (Thorson et al. 2014), highlighting opportunities and challenges to assessing the East River strait fishery and validating future restoration efforts to improve greater trophic connections and other ecological parameters.

In tandem with its scientific benefits, community science also has the power to create a constituency of people from diverse demographics who are excited about their local fishes and, ultimately, more scientifically literate and potentially engaged in conservation efforts. Participation in community science is enhanced by scientific relevance that extends beyond just an academic exercise (Phillips et al. 2019). Well-trained public participants armed with rigorous protocols and access to experts can greatly enhance the reach of scientific work, especially by expanding the temporal and spatial limits of purely academic or regulatory surveys (Dickinson and Bonney 2012). Fishes are a particularly vital subject for community-based research—they live adjacent to even the most urbanized and populous cities, they capture the imaginations of people all over the world, and they provide a strong link to other environmental concerns (Brink et al. 2018). Future research can look not just at the fish assemblages of the East River strait but also at the personal and social benefits of engaging in science-based education programs for people of all ages and backgrounds. It is not impossible to imagine that increased community science programs along the East River strait could benefit habitat restoration and result in better management of a more vibrant underwater ecosystem.

New York City fish community science has innumerable goals, including promoting environmental education, exposing the community to scientific research, creating ownership

of the scientific process, and collectively monitoring biodiversity. Moving forward, ERIA and its partnerships with public participants and anglers create a model for other communities and waterbodies to build lasting connections between stakeholders and the health of their waters. Research holds the potential to provide better information to stakeholders, policymakers, and land managers looking to make a difference for their beloved waters.

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