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Cover Photograph: Y. Alokam (left) and E. Herstoff (right) throwing a plankton net at Pebble Beach, Brooklyn Bridge Park, New York. Photo by A. Chelminski.

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Emily M. Herstoff [1]*, Maria A. Frias[1], Adrian Chelminski [1], Yacoub Alokam [1], Jimena R. Gallardo-Parada [1], Jessica Genter [2], and Michael Tessler [3,4,5]

Abstract–New York City is the largest city in the United States, yet many areas within the city are understudied in terms of biodiversity and ecology. The East River is one such area: despite the fact that tens of thousands of New Yorkers live, work, and play by this waterbody, little has been studied outside of water chemistry and phytoplankton. To begin to alleviate this paucity of data, we examined the lower East River's zooplankton communities and water characteristics during summer 2022. We found a diversity of zooplankton, from polychaete worms to larval American lobsters. Shannon diversity and evenness did not differ across sample dates, and were not influenced by water chemistry. However, the proportion of major zooplankton groups, namely copepods and gelatinous zooplankton, did significantly differ across the sampling period. For instance, gelatinous zooplankton made up a large portion of the zooplankton community for one week in June; the following week, copepod abundance dropped precipitously. The patterns we observed are likely indicative of population cycles in zooplankton abundance and diversity. Our study helps establish a baseline for zooplankton in the East River, which will be useful to monitor alongside local changes in urbanization, habitat restoration, and climate change.

Introduction

Manhattan is surrounded by three interconnected estuarine waterways, pulsing daily with a mix of freshwater and marine tides from the Atlantic Ocean. For centuries, these waterways have been used by humans as ports, fisheries, and places to dispose of human and industrial waste (Levinton and Waldman 2006, McPhearson et al. 2014, Elmqvist et al. 2013). More recently, these impacts have been lessened through the Clean Water Act, regional and local legislation, and interest groups like the WaterKeepers (Farnham et al. 2017). While this has led to improved water chemistry (Andreen 2013)—humans even sometimes venture into these waters for swimming competitions (Knechtle et al. 2014)—much of the baseline scientific information for these areas is lacking. Most research thus far has focused on chemical analyses, particularly as related to bacterial and phytoplankton abundance (Wang 2014, Fox 1991, Li et al. 2018), which is sensible given the long history of pollution in this area. However, while conservation efforts around New York City's waterways have made significant progress (McPhearson et al. 2014) and these ecosystems have been somewhat resilient to major anthropogenic impacts (O'Neil et al. 2016), the city's waterways remain understudied on a variety of fronts, such as baseline biodiversity surveys and ecological studies (Ingala et al. 2021).

The Hudson River is the best-studied of the estuarine waterways bounding Manhattan (Levinton and Waldman 2006). The Hudson River lies on the western edge of Manhattan, originating in the Adirondack Mountains and emptying into New York Harbor. The Harlem

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and East Rivers, both of which are tidal straits (Swanson et al. 1983), form the eastern bounds of Manhattan and divide the island from the Bronx, Queens, and Brooklyn. Water from the East River flows to and from the Atlantic Ocean and Long Island Sound. Some areas, such as Hell Gate, have fast currents and a history of treacherous navigation due to complex underwater topography (Rude 1923, Blumberg and Pritchard 1997). Although huge numbers of commuters traverse the East River daily (Webster and Shirley 2016), ecological data is very much lacking on the East River. Although previous work examined water characteristics and algal communities in this habitat (Li et al. 2018), to our knowledge, the marine zooplankton community remains uncharacterized. Accordingly, we studied the lower part of the East River along Brooklyn Bridge Park, which welcomes thousands of visitors daily (Webster and Shirley 2016) and has iconic views of Brooklyn Bridge, Manhattan Bridge, Governors Island, and the Statue of Liberty (Fig. 1).

We focused our study on zooplankton—the small (often microscopic), drifting animal inhabitants of aquatic habitats that form the prey base for larger consumers within these habitats. Zooplankton include well-known organisms like jellyfish (Cnidaria) and smaller organisms less familiar to the general public, but which can be highly abundant and have huge impacts on their ecosystems (Turner 2004). One example of an important, but less publicly recognized zooplankton, are the copepods: microscopic, widely abundant crustaceans that are major consumers of phytoplankton, and which in turn, are a key food source for numerous invertebrates and vertebrates alike (Lavigne 2003). Plankton also play a significant role in biogeochemical cycling (Elser and Urabe 1999) and phytoplankton provide half the global primary production in marine ecosystems (Falkowski et al. 1998). Overall, zooplankton abundance and diversity are so foundational that they are considered a metric of ecosystem health (Sherman et al. 2002). While zooplankton, including cnidarians and copepods, are likely plentiful in the East River, examinations of their natural history, including their abundance and diversity, are lacking. Plankton diversity, abundance, and community composition can also be influenced by environmental characteristics like water chemistry (Roemmich and McGowan 1995, Li et al. 2018). Accordingly, as efforts to improve water quality continue, having baseline knowledge of zooplankton community composition will better allow policy makers to assess impacts of policy changes.

Our goal was to conduct a preliminary study of the lower East River's zooplankton, report data on the zooplankton community's abundance and biodiversity, and measure water quality characteristics during summer 2022. We conducted weekly surveys of zooplankton and water quality at two study sites at Brooklyn Bridge Park, and report our findings here.

Methods

Study sites and sampling methods

Water samples were collected weekly from May 18, 2022 through July 27, 2022 at two embayments in Brooklyn Bridge Park along the lower East River in Brooklyn, NY: Pier 4 (40° 41.798′ N, 73° 59.946′ W) and Pebble Beach (40° 42.263′ N, 73° 59.430′ W) (Fig. 1A, 1B). For each sampling date, weather and tide information were noted. Pier 4 Beach is a man-made embayment, characterized by a shallow, sloping shoreline with sand and small gravel. We sampled near the rock retaining walls along the north-facing beach at Pier 4, at Marco's Cove (Fig. 1C). Pebble Beach is located between the Brooklyn and Manhattan Bridges. Its shoreline consists of some small gravel, with small to medium-sized cobble. Pebble Beach is more exposed than Pier 4 Beach; wakes from ferries and shipping boats frequently roll ashore and wash over our sampling site. At Pebble Beach, we sampled along the rock retaining walls; normally sampling the northeast corner of the beach but occasionally the southwest corner of the site, depending on how busy the beach was and shoreline accessibility (Fig. 1D).

Zooplankton samples were gathered using a plankton net (mesh size = 153 µm, mouth opening diameter = 12.7 cm). This net was chosen because it was readily available, collects macrozooplankton and does not clog as easily as finer mesh sizes, and is within the range of mesh sizes used in prior studies of this region (Rice and Stewart, 2016). However, as with any mesh-based method, both coarser and finer meshes would have resulted in somewhat different assemblages of zooplankton. At each sample site, we stood at the embayment's waterline and tossed the plankton net into the East River at a length of 5 m from shore. The weight of the net including the metal ring and plastic in the codpiece allowed the net to be tossed 5 m from the waterline. Throw distance was kept constant using a marker on the rope tow line. The plankton net was kept just under the water's surface and towed back to shore at a speed of ~1 m/sec. This was repeated 4 times, for a total of 20 m towed per sampling site, resulting in a sampling volume of 0.25 m^3 per site. We performed multiple tows to ensure enough zooplankton would

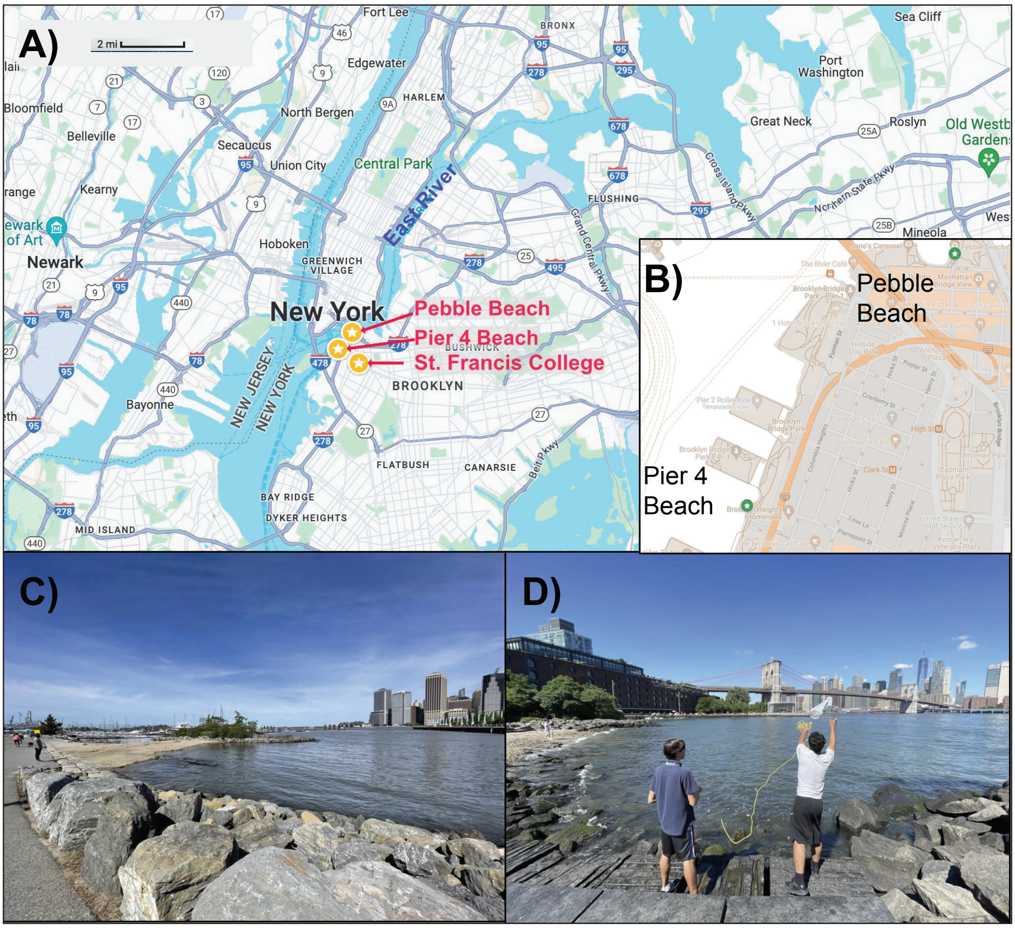

Figure 1. Study sites at the East River at Brooklyn Bridge Park, Brooklyn, NY. (A, B) Map of sites; (C) Pier 4 sampling site; (D) Pebble Beach sampling site, with Y. Alokam (right) and A. Chelminski (left) throwing plankton net. Figures 1A and 1B modified from Google Maps; Map data © 2024 by Google. Photos by E. Herstoff.

be gathered to count during analysis. After collection, the 60 mL of the sampled water with its zooplankton was poured into a labeled container. Large materials (i.e., pieces of seaweed, plastic, or sticks) were removed, and an equal volume of 100% ethanol was poured into the container to preserve the specimens. After collecting zooplankton, an additional 120 mL water sample was taken at the same site for chemical analysis.

Zooplankton identification, chemistry, and statistics

For each sample site and date, one sample was taken for zooplankton and another sample was taken for water analysis.

Zooplankton were identified and counted within broad groups (ex: polychaetes, amphipods, etc.) and copepods were identified and counted within order (Harpacticoida, Cyclopoida, or Calanoida) using a regional taxonomic key (Johnson and Allen 2012).

For water chemistry measurements, water samples were gathered in small plastic cups and brought to the laboratory for analysis within 30–60 minutes after collection. We used a Vernier LabQuest 2 to measure salinity via a salinity sensor, turbidity via a turbidity sensor, and percent transmittance via a UV-VIS spectrophotometer of the field-collected water sample. Sample containers were thoroughly rinsed with fresh water and dried for reuse next week after analysis was complete.

When considering the zooplankton community through time, we focused on the most abundant categories of organisms within arthropod- and non-arthropod zooplankton. For arthropods, amphipods were identified to the familial level, copepods to the ordinal level, all other arthropods were identified as larval stages within broad categories such as barnacles, lobsters, crabs, etc. Non-arthropods were categorized as gelatinous (cnidarians ctenophores, salps, doliolids, and appendicularia), fish eggs and larvae, gastropods, and polychaetes. Because the overall count of organisms for any particular sample date varied widely, we examined the daily total counts of organism abundance. Also, no zooplankton were collected from Pier 4 on the last sample date (July 27, 2022).

To analyze our data, we first reviewed the total counts of weekly organism abundance samples to see if there were patterns during the course of this study at our two sample sites. We used R (R Core Team 2020) along with ggplot2 (Wickham 2009) for visualization. Next, we used paired t-tests to examine water quality at the two sites, as the sites represent paired data, and we used Vegan (Oksanen et al. 2019) to calculate Shannon Diversity Indices and Evenness. Lastly, because we only found one copepod at both of our sample sites on June 29, 2022, we compared copepod abundance on this date to all other sample dates using a one-sample t-test.

Results

Zooplankton

Zooplankton from seven phyla and 13 classes were found (Table 1). We observed a mixture of adult and larval animals.

Community composition through time

Daily community composition at the two study sites is shown as the proportion and total counts of arthropod and non-arthropod zooplankton (Tables 2–3). When reviewing the overall abundances of organisms through time (Tables 2–3), we decided to not include rare and sporadically encountered organisms (e.g., Arachnida, Gastropod, Appendicularia, Thaliacea; Table 1) in the analyses below.

When visually inspecting organism abundance through time at our two sample sites (Tables 2–3), we found that copepods were generally abundant throughout the summer and usually made up about half of the zooplankton collected from a sample site on any particular day. The greatest total organism abundance was observed on June 8, 2022, which was mostly copepods (Pier 4: 108 total organisms, 55% copepods; Pebble Beach: 172 total organisms, 78% copepods). However, there were some notable exceptions to this trend: Copepods were in very low abundance at Pier 4 from June 15 to July 6, and at Pebble Beach from June 29 to July 6. On June 29, 2022, one copepod was found at each of our sample locations at Pier 4 and at Pebble Beach. This was significantly lower when compared to the total number of copepods

Table 1. Zooplankton taxa from the East River at Brooklyn Bridge Park, Brooklyn, NY.

Phylum	Major group	Common names & notes	Stage
Annelida	Polychaete, Class		Larvae
Arthropoda	Amphipoda, Order	Scuds (various species)	Adult
		Caprellidae (Skeleton shrimp)	Adult
	Arachnida, Class	Mite	Adult
	Cirripede, Subclass	Barnacle	Larvae
	Cladocera, Order	Water flea	Adult
	Collembola, Subclass	Springtail	Adult
	Copepoda (copepod), Subclass	Copepodites	Misc. copepods of young stages
		Calanoid	Adults and copepodites
		Cyclopoid	Adults and copepodites
		Harpacticoid	Adults and copepodites
	Decapoda, Order	American lobster	Larvae
Bryozoa			Larvae
Chordata	Actinopterygii (ray-finned fish), Class		Egg; larvae
	Appendicularia (larvacean), Class		Adult
	Thaliacea (salp), Class	Doliolid	
Cnidaria, Ctenophora (Gelatinous zooplankton)	Medusozoa, Subphylum (true jellies) Tentaculata, Class (comb jellies)		
Mollusca	Gastropod (snail), Class		Adult

Table 2. Daily organism count and percentage of sample abundance for arthropod and non-arthropod zooplankton at Pier 4 on the East River, Brooklyn Bridge Park, Brooklyn, NY. Empty cells indicate no organisms of that type were collected. Dates are shown as month/day/year.

Site: Pier 4

	Date		5/18/22	5/25/22	6/1/22	6/8/22	6/15/22	6/29/22	7/6/22	7/13/22	7/20/22	7/27/22
	Total invertebrate count		21	71	22	108	75	49	5	42	20	
Arthropods	Copepods	Count	9	64	10	59	2	1	2	39	14	
		Percent	42.86	90.14	45.45	54.63	2.67	2.04	40.00	92.86	70.00	
	Amphipods	Count	3	1		3		38	2		1	
		Percent	14.29	1.41		2.78		77.55	40.00		5.00	
	Decapods	Count	7	1		2				1		
		Percent	33.33	1.41		1.85				2.38		
	Cladocerans	Count		1	2	27					1	
		Percent		1.41	9.09	25.00					5.00	
Non-Arthropods	Fish	Count			3	11	42	10	1		2	
		Percent			13.64	10.19	56.00	20.41	20.00		10.00	
	Tunicates	Count								1		
		Percent								2.38		
	Gastropods	Count			1	2	1				1	
		Percent			4.55	1.85	1.33				5.00	
	Gelatinous Zooplankton	Count					29					
		Percent					38.67					
	Polychaetes	Count	2	4	6	4	1			1	1	
		Percent	9.52	5.63	27.27	3.70	1.33	0.00	0.00	2.38	5.00	

Table 3. Daily organism count and percentage of sample abundance for arthropod and non-arthropod zooplankton at Pebble Peach on the East River, Brooklyn Bridge Park, Brooklyn, NY. Empty cells indicate no organisms of that type were collected. Dates are shown as month/day/year.

	Site: Pebble Beach											
	Date		5/18/22	5/25/22	6/1/22	6/8/22	6/15/22	6/29/22	7/6/22	7/13/22	7/20/22	7/27/22
	Total invertebrate count		27	33	16	172	18	56	27	14	16	40
Arthropods	Copepods	Count	26	27	7	134	15	1	7	7	9	21
		Percent	96.30	81.82	43.75	77.91	83.33	1.79	25.93	50.00	56.25	52.50
	Amphipods	Count				15		45	8	1	5	6
		Percent				8.72		80.36	29.63	7.14	31.25	15.00
	Decapods	Count		1	1		1		7			
		Percent		3.03	6.25		5.56		25.93			
	Cladocerans	Count			1	7	1				1	
		Percent			6.25	4.07	5.56				6.25	
Non-Arthropods	Fish	Count			3	3	1	10	4		1	9
		Percent			18.75	1.74	5.56	17.86	14.81		6.25	22.50
	Tunicates	Count	1	1		1				1		1
		Percent	3.70	3.03		0.58				7.14		2.50
	Gastropods	Count		1	1	3				2		2
		Percent		3.03	6.25	1.74				14.29		5.00
	Gelatinous Zooplankton	Count										
		Percent										
	Polychaetes	Count		3	3	9			1	3		1
		Percent		9.09	18.75	5.23			3.70	21.43		2.50

found at all other sample dates and locations (Tables 2–3, for both sites; one-tailed t-test, t = 3.08, df = 18, P = 0.0065). This period also coincides with a greater proportional abundance of predators like fish, gelatinous zooplankton, and some caprellid amphipods. Notably, gelatinous zooplankton were only found at Pier 4, and only on one sample date (June 15, 2022), where they made up ~40% of the sample.

Community diversity metrics are plotted in Fig. 2. Evenness is the relative abundance of species within a community; communities that have very unequal relative abundances are closer to 0, and communities where relative abundances are nearly equal are closer to 1. The Shannon Diversity Index calculates community diversity using both the total number of species and the evenness of species abundances in the habitat; values range from 0 (a community is only made of one species) to higher numbers (indicating the community contains more species). Sites were similar overall, and there were no significant differences in diversity metrics between sites across time (paired t-tests; Shannon Diversity: t = −0.98, df = 8, p-value = 0.36; Evenness: t = −0.85, df = 8, P = 0.42). Across the summer sampling dates, both metrics fluctuated, with low points in diversity occurring from mid through late June—which is the point at which the gelatinous zooplankton (Tables 2–3) became dominant. The one-way ANOVA found no significant relationship between daily measurements of evenness or Shannon Diversity and site and water chemistry.

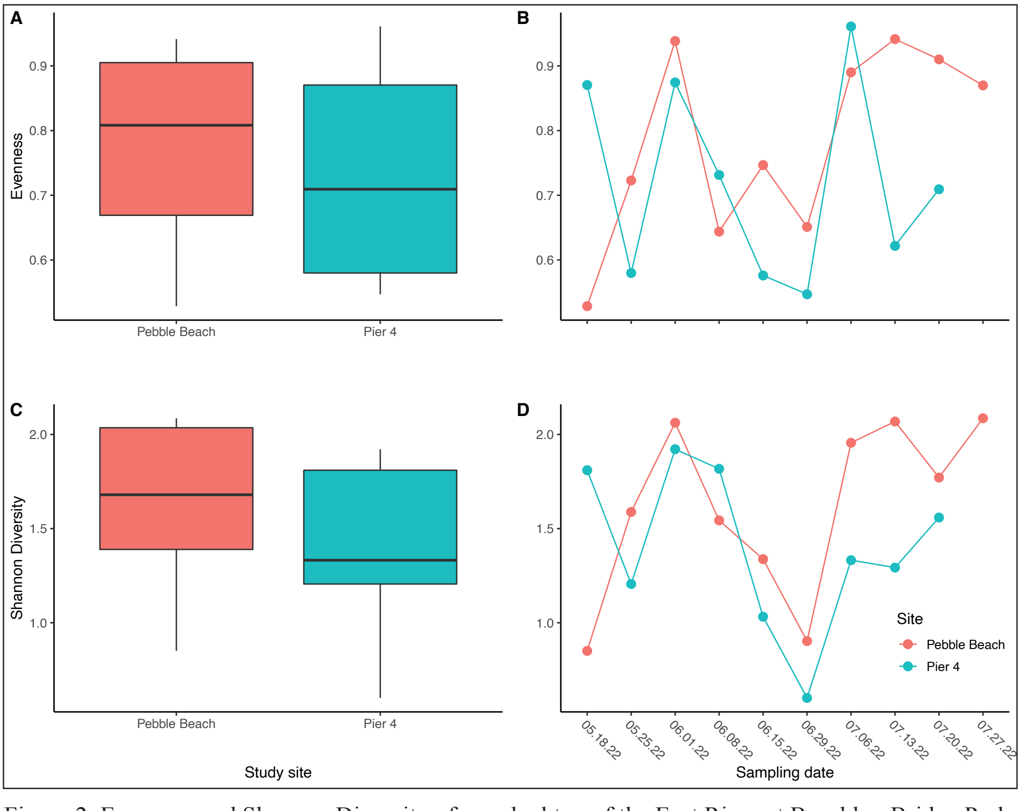

Figure 2. Evenness and Shannon Diversity of zooplankton of the East River at Brooklyn Bridge Park, Brooklyn, NY. Colors indicate sampling sites (pink = Pebble Beach; blue = Pier 4). Panels (A) and (C) show box-and-whisker plots; the line in the box shows the median, the box outline shows the 1st and 3rd quartiles, whiskers show minimum and maximum values. Panels (B) and (D) show line graphs representing the diversity metric calculated for each sampling date and site throughout the summer.

Water chemistry

Water chemistry throughout the course of the summer at the two study sites is plotted in Fig. 3. Transmittance was significantly different between sites throughout the summer (paired t-test, $t = 78.06$, $df = 8$, $P < 0.0001$), showing a rise in July. Although salinity was relatively consistent between sites throughout the summer, we found a significant difference between sites (paired t-test, $t = 6.87$, $df = 8$, $P = 0.00013$). There was a notable dip in salinity at Pebble Beach on July 6, 2022, which could be a measurement error. Turbidity was significantly different between sites throughout the summer (paired t-test; $t = -34.93$, $df = 8$, $P < 0.0001$), with high degrees of fluctuation. The one-way ANOVA found no significant relationship between the daily total number of organisms and site or water chemistry.

Discussion

Overview

Our study helps to establish baseline ecological and biodiversity data on East River zooplankton, a critical component of aquatic food webs. We found a variety of zooplankton across our samples, with taxa ranging from larval lobsters and barnacles, to polychaete worms and tunicates. Shifts in organism abundance occur for some (e.g. gelatinous zooplankton and copepod populations) major taxonomic groups. Most other major groups were proportionately more consistent. The dynamics between gelatinous zooplankton and

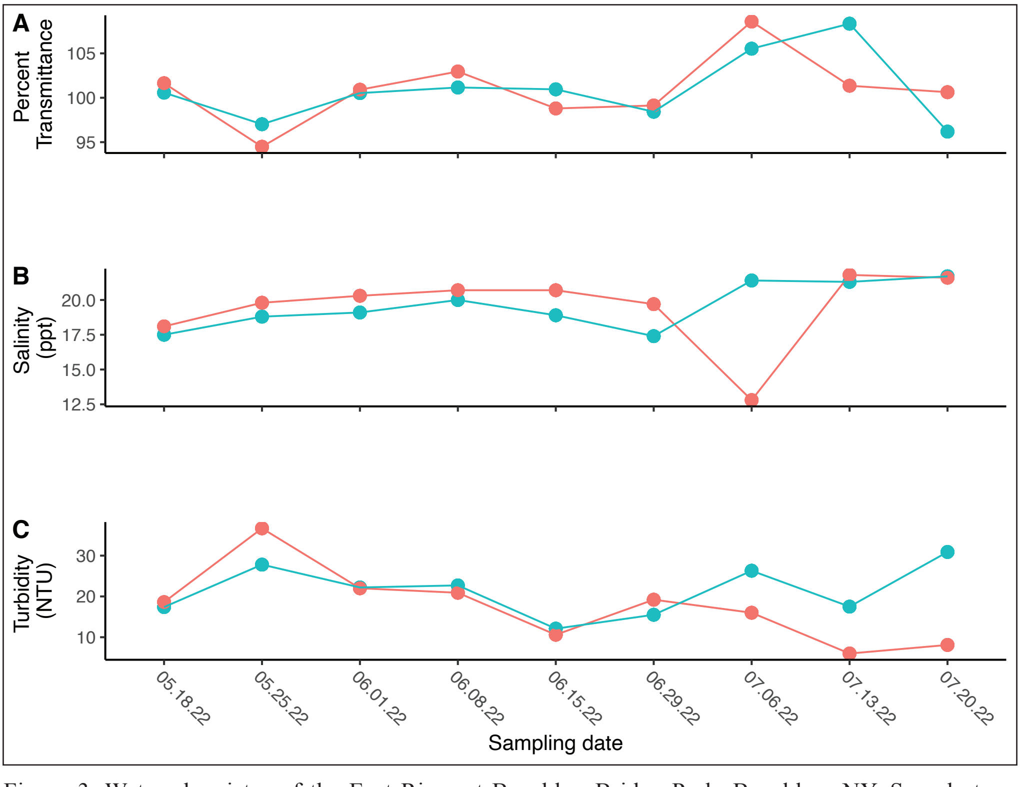

Figure 3. Water chemistry of the East River at Brooklyn Bridge Park, Brooklyn, NY. Sample type shown on vertical axis; sample date shown on horizontal axis. Colors indicate sampling sites (pink = Pebble Beach; blue = Pier 4).

copepods may represent a predator-prey cycle and match previous research in nearby Long Island Sound, as discussed below. Our data suggest that, despite its history of pollution and urbanization, the East River has a dynamic set of zooplankton.

Zooplankton community composition

Zooplankton included holoplankton like copepods, cladocerans, and salps, and meroplankton like barnacles, snails, and lobsters. For simplicity, our analysis examined patterns in the most common groups of organisms. We found that some groups, especially copepods, made up a large portion of the sample throughout the summer. In contrast, most groups of organisms—e.g. gelatinous zooplankton and cladocerans—were observed for short periods of time or in low abundances throughout the summer.

Our findings match a previous study (>65 years ago) in Long Island Sound (Deevey 1956): copepods dominated zooplankton samples, with some groups, like Cladocerans, barnacle larvae, and polychaetes being relatively abundant at some points throughout the sampling period. These other groups can be important grazers, and some, like barnacle larvae and polychaetes, eventually settle to the benthos as adult organisms. Lastly, our findings match this previous work in Long Island Sound, where zooplankton peaked in June (Deevey 1956).

Similar to our observations in the East River, previous work in nearby Long Island Sound found that copepods dominate the zooplankton community, with gelatinous zooplankton like the ctenophore, *Mnemiopsis leidyi* Agassiz (Sea walnut) and the jellyfish, *Cyanea capillata* Linnaeus (Lion's mane jellyfish) becoming dominant at some points during summer sampling (Turner 1982, Rice and Stewart, 2016). Given that our study sites are connected to Long Island Sound via the East River, it is possible that our gelatinous zooplankton consist of these same species. However, to confirm this, zooplankton identification would have to be performed at the species level, which is beyond the scope of our study. Copepods are an important food for many organisms, from forage fish to seabirds and marine mammals (Lavigne 2003). Of potential importance to our study, gelatinous zooplankton like true jellyfish (Scyphozoa, Cnidaria) and comb jellies (Ctenophora) are major consumers of copepods. For example, in a Long Island Sound estuary, *Cyanea* jellyfish medusa were abundant predators of copepods (Brewer 1989). A study on the ctenophore, *Mnemiopsis leidyi* found that copepods were consumed, but were at a lower abundance within the predator's gut compared to slow-moving zooplankton like decapod and gastropod larvae (Schroeder et al. 2023). Because gelatinous zooplankton like jellyfish and comb jellies are important and voracious predators on grazing zooplankton like copepods, gelatinous zooplankton can have a top-down influence on community diversity and organism abundance, and allow increased phytoplankton abundance (Deason and Smayda 1982, Schneider and Behrends 1998). Similarly, gelatinous zooplankton are predicted to control copepod populations in the northeast Atlantic (Davis 1984). In our work, we saw increased percent transmittance in July, which could possibly relate to fluctuations in both gelatinous zooplankton and copepod abundance (Tables 2–3, Fig. 3).

These findings are important because some predictions suggest that future, warmer water environmental conditions may result in more jellyfish (Richardson et al. 2009). For example, hydromedusae were more abundant in years where mid-Atlantic bays were lower in salinity (Oghenekaro and Chigbu 2019), and ctenophores were found to benefit from warmer temperatures (Slesinger et al. 2020). Future climate conditions may benefit gelatinous zooplankton, and these changing conditions could shift community structure and composition of the remaining community, and subsequently result in large changes to biogeochemical cycling (Beaugrand 2009). Because gelatinous zooplankton play such an important role in controlling the abundance of key zooplankton groups like copepods, future work in the East River should more carefully monitor metrics like water quality and water chemistry, and phytoplankton and zooplankton community diversity and abundance. Understanding how this may shift in future conditions may help us better understand how ecosystem services in the East River may be influenced by climate change.

Water chemistry

Water chemistry varied throughout the summer. We did not see a clear link between chemical and physical characteristics in the water and changes in biota, with the potential exception of changes in transmittance and turbidity that took place roughly when the dominant taxa shifted from copepods to a bloom of jellies. Future work should examine this potential abiotic/biotic link. This is especially important because copepods tend to dominate zooplankton communities (Escribano et al. 2007), and copepod communities can be influenced by environmental conditions, like water flow and wind stress patterns (Fontana et al. 2016), and temperature and salinity (Leandro et al. 2007, Ambler et al. 1985).

Water chemistry was similar between sample sites, other than a few days showing strong differences (e.g. salinity on July 6, 2022; Fig. 3B). Similar measurements of water chemistry presumably reflect the close proximity and physical features of the sites (0.8 miles apart; Fig. 1). This is important for future work, as sampling at one site at Brooklyn Bridge Park can likely be a good proxy for nearby sites.

Conclusions, limitations, and future directions

Our baseline data on summer zooplankton communities and water chemistry in the East River will be useful as changes in restoration, urbanization, and climate change continue to impact New York City. Please note that our findings are just the beginning of studies on the East River. Our data are limited to a single season and focus on broad groups of taxa for broad ecological comparisons. With future fine-grained research, multi-year studies, and studies across more seasons, nuance is sure to arise. We hope this work helps to spark further interest and exploration of East River biodiversity and ecology, as many types of organisms exist here that remain poorly examined.

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Competing interests

The authors declare no competing interests.

Author contributions

E.M. Herstoff designed the experiment. E.M. Herstoff, A. Chelminski, Y. Alokam, J.R. Gallardo-Parada, and J. Genter gathered the data. E.M. Herstoff, and M. Tessler performed the data analysis. E.M. Herstoff, and M. Tessler wrote the manuscript with support from A. Chelminski, Y. Alokam, and M.A. Frias. The final draft of the manuscript was read and approved by all authors.

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