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URBAN RIVERS AS SOCIAL-ECOLOGICAL SYSTEMS: AN EXAMINATION OF HISTORY & ECOLOGY IN THE MIAMI RIVER

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To: Dean Michael R. Heithaus
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This thesis, written by Daniela Brigitte Daniele, and entitled Urban Rivers as Social-Ecological Systems: An Examination of History & Ecology in the Miami River, having been approved in respect to style and intellectual content, is referred to you for judgment.

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ABSTRACT OF THE THESIS

URBAN RIVERS AS SOCIAL-ECOLOGICAL SYSTEMS: AN EXAMINATION OF HISTORY & ECOLOGY IN THE MIAMI RIVER

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Rivers have played significant roles in development of cities worldwide. Increasing urbanization has diminished the quality of lotic resources and altered the way in which humans interact with rivers by converting free flowing rivers into heavily altered systems. The Miami River in South Florida, USA, provides a model case for examining urban rivers as social-ecological systems. Research on urban rivers in general and the Miami River is limited. To date, how the urbanization of Miami and surrounding areas may have disrupted social-ecological riverine connectivity has not been studied. To fill this gap, I compiled an environmental history of the river to examine how connectivity and quality of the river changed. This research integrated long-term water quality data, interview, observational, and archive data. Data show an improvement in water quality in the early to mid-2000s, likely linked to emerging policies and restrictions. This research will add to growing knowledge of urban rivers as social-ecological systems.

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A SOCIAL-ENVIRONMENTAL HISTORY OF THE MIAMI RIVER, FLORIDA, USA

1.1 ABSTRACT

Rivers have largely influenced human settlement and played significant roles in development of cities worldwide. Nevertheless, increasing urbanization has diminished the quality of lotic resources and altered the way in which humans connect and interact with rivers, in part by converting free flowing rivers into heavily altered systems. The Miami River in South Florida, USA, provides a model case for examining urban rivers as social-ecological systems. The Miami River was 5 miles long, in its original extent, and whose history is intertwined with the city that bears its name. The river is now a heavily altered system as a consequence of urban development and years of use as a dumping area for waste. Research on urban rivers in general and the Miami River is limited. To date, how urbanization of Miami and surrounding areas may have disrupted social and ecological riverine connectivity has not been studied. To fill this gap, I compiled an environmental history of the river from 1500 to 2020 to examine how connectivity of the Miami River has changed. This research will add to growing knowledge of urban rivers as social-ecological systems, with a focus on historical changes and alterations of river connectivity.

Key words: urban rivers, social ecology, ecological river connectivity, social connectivity, environmental history

1.2 INTRODUCTION

River connectivity is one of the most important properties that underpins the function of lotic (flowing water) ecosystems, supports biological assemblages, and influences human and social interactions with rivers. In an ecological context, the concept of river connectivity and its importance emerged from the River Continuum Concept (Vannote et al., 1980) that eventually developing into a four-dimensional ecological framework for lotic (flowing water) ecosystems (Ward 1989). Three spatial dimensions comprise this framework as proposed by Ward (1989). The first, longitudinal connectivity, concerns itself with upstream-downstream interactions, or the longitudinal dimension along which processes like fish migration or nutrient spiraling occur. The second, lateral connectivity, refers to river to riparian zone or floodplain interactions like nutrient exchange, fish migration to floodplain nursery areas and tributaries, and allochthonous material input to the stream. The third, vertical connectivity, refers to surface water to groundwater interactions. Time comprises the fourth dimension, referring to the fact that all processes along the three spatial pathways happen over certain periods.

The concept of multidimensional river connectivity has been applied to understand rivers in many different contexts such as restoration, riverfront development, and management (Pringle, 2001; May, 2006; Dunham et al., 2018) but also has been adapted to consider the human and social relationships with rivers. For example, Kondolf and Pinto (2017) use three of the original dimensions applied in ecological space—longitudinal, lateral, and vertical—to additionally describe how human uses of rivers in urban areas occur along multiple dimensions as well. In their framing, longitudinal social connectivity focuses on human interactions and movement, such as navigation, in the upstream-downstream dimension. Lateral social connectivity refers to human and social interactions on the waterfront and bank to bank interaction. Vertical social connectivity refers to human access to an urban river, either by physically getting into the water or through visual engagement.

River connectivity, in both ecological and social contexts and in the various dimensions, changes over time in response to natural processes and human alterations of rivers. For instance, longitudinal ecological connectivity could be altered through the removal of bedrock or channelization, an action which may increase longitudinal social connectivity by facilitating increased navigation (Kondolf and Pinto, 2017). Removal of bank vegetation reduces lateral ecological connectivity but can increase lateral social connectivity by facilitating human access to the water and from bank to bank, if infrastructure like a bridge is erected. Lateral social connectivity can increase as lateral ecological connectivity decreases since vegetation is removed to make space for development and infrastructure along shorelines. Vertical ecological connectivity can be affected when a river is dredged for lengthening and widening purposes or parts of the channel culverted or paved over, like the Los Angeles River, California (Gumprecht, 2001) limiting surface water to ground water interactions. These same actions can affect vertical social connectivity as well by decreasing physical or visual human access to the river like in the Nile River as it passes through Cairo, Egypt (Gohar and Kondolf, 2020).

In this study, I use the concept of river connectivity as an analytical lens for examining change over time in the Miami River, Florida, USA. I review the social-environmental history of the Miami River over a >500-year period, 1500-2020. I examine ecological change and human and social relationships with the river and identify distinct periods marked by major historical events. I document general conditions of river connectivity, in both ecological (Ward, 1989) and social terms (Kondolf and Pinto 2017), for each of these distinct time periods.

1.3 STUDY SITE AND METHODOLOGY

In its unaltered state, the Miami River was 7.42 kilometers in length and drained eastward to the Atlantic Ocean through the center of the modern-day City of Miami, FL (Gaby, 1993; George, 2013). However, from 1909 to 1914, the Miami River was linked with a channelization project that resulted in the Miami Canal, which extends for around approximately 145 kilometers and connects the Miami River with Lake Okeechobee (Figures 1.1 and 1.2); this is the present extent of the Miami River – Miami Canal system today.

Prior to anthropogenic changes, the headwaters of the Miami River were rapids located on the river's north fork. The unaltered river was formed by two tributaries, the north and south fork. The rapids on the north fork had a drop of 2.45 meters, whereas the south fork also had rapids but they were much smaller in size and elevation. A large spring pool (3 meters in depth and 23 meters in width) above the north fork was considered its main source of water, in addition to a few smaller pools (Gaby, 1993). Additionally, the Miami River's flow depended on rainfall and overflow from the Everglades (Gaby, 1993). Vegetation composition varied along the river, ranging from hardwood hammocks, coontie (*Zamia pumila)*, Caribbean pine, palmetto (*Serenoa repens cinerea*), and mangroves, while other areas were marshy and muddy flats (Gaby, 1993).

My review of social and environmental conditions over time focused mainly on the original extent (7.42 km) of the Miami River, although the larger context of the Miami River – Miami Canal system was considered.

To examine change over time in the Miami River, I compiled a social-environmental history of the Miami River by reviewing existing available literature from 1500 to 2020. I reviewed archival data at the HistoryMiami Museum and a Miami historian's classification of major events in Miami (Table 1; P. George, HistoryMiami, pers. comm.) which offered information on the history of Native American inhabitants, colonial settlers, vegetation and life in the river, agriculture, and major ecological and social changes relating to the river. By searching key words in the library catalog system at University of Florida and Florida International University, I filtered relevant results that focused on historical data as well as development of Miami and the river. Historical tours of the Miami River, led by South Florida historian Dr. Paul George, served as reconnaissance trips. Additionally, searches on Google with key words such as "Miami River Florida history," "Miami River Florida Tequesta," "Miami River Florida restoration" resulted in newspaper articles from the Miami Herald and the SunSentinel, as well as public university web sources and photographs. The compilation of this information led to categorization of periods focusing on themes related to the river, ranging from unrestricted natural flows and minimal human impact to the river, to war, development, and restoration.

The compilation of the river's social-environmental history led to categorization of eras where major events involving the river were used as a start or end dates for eras. For each era, based on information from the literature and from historical records, I documented major changes or conditions that related to ecological riverine connectivity and social riverine connectivity as defined by Ward (1989) and Kondolf and Pinto (2017). Connectivity was used as a framework to examine change over time. Changes in social-ecological connectivity were examined by exploring how the river was changed by establishment of crops, houses, hotels, and marinas on the river, removal of native vegetation, construction of bridges, usage of the river (more recreational or industrial), and how human population growth differed through each era. I considered three spatial dimensions of riverine connectivity: longitudinal, lateral, and vertical in both ecological and social contexts. The Miami River was analyzed as a social-ecological urban river system, in which both ecological and social factors influence and impact one another (Dunham et al., 2018).

Additionally, I conducted six telephone interviews (IRB-20-0571), with employees of the City of Miami (1), Miami River Commission (1), DERM (1), boat captains (2), and archeologists (1). The interviews provided information that served as supplemental, observational data for the last two eras.

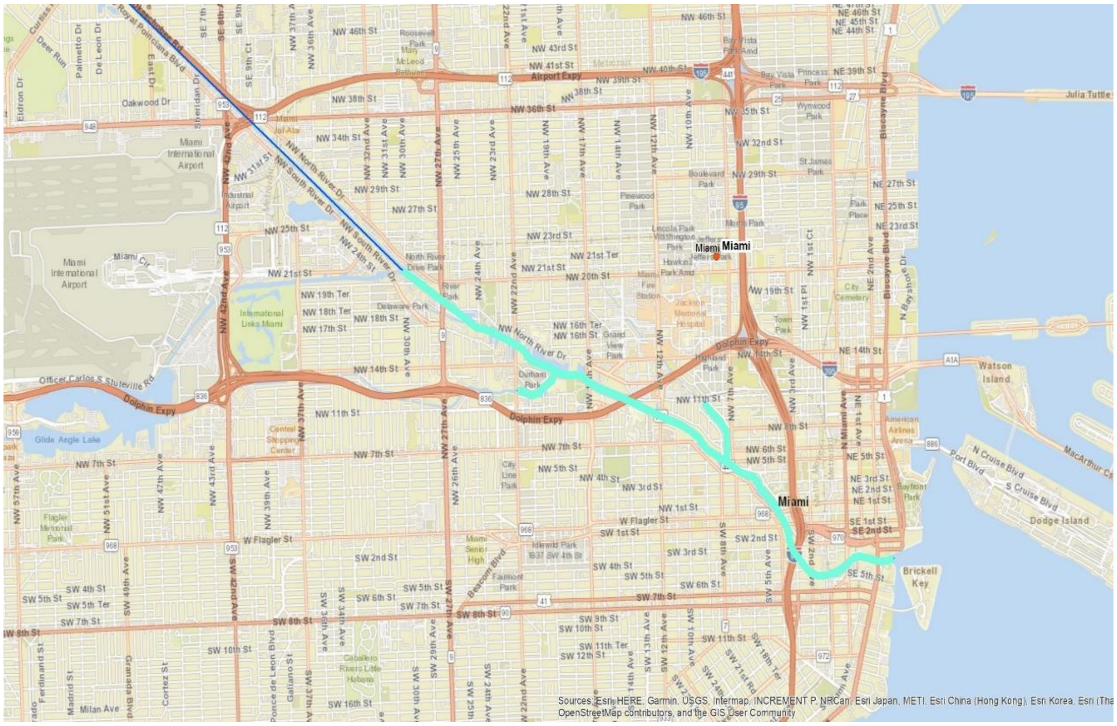

Figure 1.1: The original extent of the Miami River, connecting to the Miami Canal.

Figure 1.2: Miami River connected to Lake Okeechobee in blue line through the Miami Canal passing through protected and agricultural areas.

1.4 RESULTS

The history of the Miami River can be divided into eight distinct eras from 1500 to 2020. Each era marks a specific period in the river's history (Table 1-1), parallel to historian Dr. Paul George's classification of major events in Miami. The river provided sustenance and drinking water, and access to important locations such as Biscayne Bay and the Everglades. As settlers began to develop the banks of the river with crops and infrastructure, the river served as a tourist destination and an access point for the Caribbean. Over time, the Miami River evolved into a working river, where industry and recreation mixed. Throughout each era, connectivity in any one-dimension changed (Table 1-2) as a consequence of anthropogenic changes impacting human-river interactions in terms of connectivity, but also how rivers are impacted ecologically by these changes.

Table 1-1: The history of the Miami River divided into eight eras, each with a different theme.

Era 1 (1200 BC - 1512)	Documented origins of the Miami River and its early riparian inhabitants, the Native Tequesta people
Era 2 (1513 - 1816)	European arrival to South Florida and the Miami River marked by little changes in river morphology and emerging different social climate
Era 3 (1817-1869)	Miami River's role in Seminole Wars and events that followed
Era 4 (1870 - 1895)	Homesteaders began moving to Miami, settling on shores of the river

Era 5 (1896 - 1919)	Miami River underwent changes such as infrastructure construction on both banks
Era 6 (1920-1959)	Population increase and an emerging economy that depended on the river
Era 7 (1960 - 1999)	Further urbanization on banks while moving towards restoration of the urban river
Era 8 (2000 – now)	Restoration and luxury on a fully working river

Table 1-2: Social and ecology connectivity throughout eras.

	Ecological Connectivity (Ward, 1989)			Social Connectivity (Kondolf and Pinto, 2017)		
Period	**Longitudinal**	**Lateral**	**Vertical**	**Longitudinal**	**Lateral**	**Vertical**
<u>Era 1</u> **1200/1500-1512** Connectivity reflected original state of the river	Longitudinally connected to Biscayne Bay Rapids on the North fork of the river due to Everglades overflow Nutrient cycling and aquatic migration uninterrupted	Natural tributaries: Wagner Creek, North fork, South fork Allochthonous material and habitat	Spring as another main source for the river	Tequesta travelled up and downstream through canoe or swimming	Trade, communication gathering food, shelter along banks, space for ceremonies, recreation	Fishing from the bank tops and collecting freshwater
<u>Era 2</u> **1513-1816** Connectivity reflects Era 1				Increased as non-native groups arrived on the mouth of river	Increased as missions and shelter placed along banks	
<u>Era 3</u> **1817-1869** Connectivity decreased ecologically as human activity increased		Decreased as vegetation was removed		Increased as river was used for navigation and transportation during war. Coontie mill powered by rapids	Increased as Fort Dallas constructed on north fork Burial mounds for casualties	
<u>Era 4</u> **1870-1895**		Decreased more		Trading posts, travel to Everglades,	Increased as more attractions and homes	Fishing, walking, diving, gathering fruits, canoeing,

Last era to see the Miami River in original form		vegetation was removed		Biscayne Bay, tourism on river, rapids, and Everglades excursions Florida East Coast Railway connected Miami to other cities	appeared on the banks Aesthetic appreciation of river and bay	and washing clothes

	Ecological Connectivity (Ward, 1989)			**Social Connectivity (Kondolf and Pinto, 2017)**		
Period	**Longitudinal**	**Lateral**	**Vertical**	**Longitudinal**	**Lateral**	**Vertical**
<u>Era 5</u> **1896- 1919** Major changes in connectivity as the river was morphologically changed and infrastructure erected	Increased due to loss of rapids Nutrient dispersal disrupted as flow from the Everglades disconnected Increased in 1912 due to construction of Miami Canal as Miami River connected to Lake Okeechobee	Decreased due to construction, snag removal, flood protection Decreased as banks were now further apart.	Dredging disrupted the source of the river, altering sediments. Deepening of river by dredging disrupted connectivity	Flagler's railroad near Miami River brought people to Miami and its river Travel along gradient increased since navigation was now uninterrupted from removed rapids	Increased as bridges were constructed on banks Trading between settlers and Native Americans	Increased as taller buildings were constructed. Marinas were also constructed, adding new vertical interactions on the surface of the river
<u>Era 6</u> **1920-1959** Miami River continued to see	Altering connectivity by changing the source of the river resulted in	Decreased vegetation, sediment turnover,	Dredging and deepening of river	Increase from real estate boom, production for WWII in marinas,	Displayed through recreational and	Construction of high-rise buildings

fast growth and change on its banks	accumulation of pollutants that degraded water quality through disruption of sediment transport and flows	bank flooding from hurricanes Heavy development decreased connectivity Increase due to canal networks and widening of river	decreased connectivity in hyporheic zone and stream bed	Brickell Avenue Bridge, resulting in pollution Hurricane's disruption on infrastructure decreased connectivity Sewage pipes emptying into the river Smuggling during Prohibition Era	transportation travel	increased connectivity Such as swimming, fishing, and canoeing. Connectivity decreased through loss of the Miami River as a freshwater drinking resource

	Ecological Connectivity (Ward, 1989)			**Social Connectivity (Kondolf and Pinto, 2017)**		
Period	**Longitudinal**	**Lateral**	**Vertical**	**Longitudinal**	**Lateral**	**Vertical**
<u>**Era 7**</u> **1960-1999** Degraded water quality began to gain attention. Connectivity did not change as drastically as previous eras,	Degraded quality due to increased connectivity Bridges and structures above river impacted connectivity as flow and movement of organisms disrupted			Miami River became a working river increasing connectivity through Port of Miami. Tourism and trade on increased Illicit drugs on port resulted in issues	Riverwalk increased connectivity Working river identify altered connectivity: less recreation, more industrial, production, housing on its	Decrease in activities interacting with water directly due to increased presence of large ships on surface of river Increased through

construction impacted social connectivity.				between drug cartels and authorities (Cocaine Cowboys)	banks rather than on river itself Tent City, home to immigrant refugees on south fork	construction of Miami Metro Mover above the river, sacrificial animals for religious rituals and illicit drugs
<u>Era 8</u> **2000- Present** Ecological connectivity did not change as much as Eras 4 and 5. Working river identity as interactions range from industrial to commercial to residential		Constantly changing due to ongoing infrastructure projects Flood control structures and canals altered connectivity	Dredging of river to remove contaminated sediments	Tugboat and freight boats, yachts, fishing boats, diesel boats, and recreational boats Opening of bridges on the river increase connectivity on the river but decreases when bridges are closed.	Construction developed into identifiable Miami skyline Miami River Day on the banks, dog parks, community gardens, shopping centers, and restaurants Bridges on the river increase connection when closed	Decreased connectivity: less diving and swimming but increased as new interactions merged on the vertical dimension such as interactions with the river from high-rise buildings (lounging and recreation)

Era 1: Origins of the Miami River and Its Early Inhabitants (1500 - 1512) The Miami River is considered to have inherited its name from Lake Mayaimi (known as Lake Okeechobee today), meaning big water (Simpson, 1956), and from a Tequesta word meaning “sweet water” (Gaby, 1993; George, 2013). Early human settlements depended on the Miami River for freshwater and sustenance (Jackson et al., 1973; WLRN, 2015; National Park Service, 2017; Trail of Florida's Indian Heritage, 2021). Before the Tequesta, Paleo-Indians inhabited the banks of the Miami River on the south side of Biscayne Bay (George, 1996; George, 2013). The Paleo-Indians are the earliest known human settlements in this area (Carr, 2012), with evidence dating to around 10,000 BC (George, 1996). They are the first known inhabitants of the New World during the Pleistocene era. This was the last ice age era where large mammals were present, and the Paleo-Indians roamed what is now North America and Florida (Pentacrest Museums, 2015; Milanich, 1998). According to archeological records, the Paleo-Indians did not reach South Florida from Asia until 3000 B.C. (Carr, 2012).

In 1500 BC, the ancestors of the Tequesta moved into South Florida from the northern part of the continent and in 500 BC, small groups of Native Americans formed a confederation, the Tequesta (Glauber, 2017). The Tequesta inhabited the banks of the Miami River and records on the Tequesta’s diet and lifestyle allows insight to ecology and human connections to the river. Historically, the headwaters of the Miami River provided access to the Everglades (WLRN, 2015), and the river corridor served as a critical link between the eastern Everglades and Biscayne Bay (Carr, 2012). Through archeological digs and the discovery of the Miami Circle, believed to be a large ceremonial cite, chief home, or temple for the Native Tequesta, it is theorized that the main Tequesta village was located at the mouth of the Miami River (Brochu, 2000; Carr, 2012; Trail of Florida's Indian Heritage, 2021). The Miami River provided plentiful resources for the Tequesta and was linked to arts and religion (Brochu, 2000; National Park Service, 2017; Trail of Florida's Indian Heritage, 2021). For example, there were many turtles and porpoises, crabs, manatees, alligators, deer, and shellfish. On the edge of the Everglades, the dominant shells in middens were turtle shells (Gaby, 1993; Brochu, 2000; Historical Society of Palm Beach County, 2009). Nets allowed the fish to be kept and preserved in the ocean, and the abundant resources of the Miami River and the bay allowed the Tequesta to be successful despite not having a society based on agriculture (WLRN, 2015). Vegetation along the river allowed a variety of fruits, nuts, and game to be acquired by the Tequesta. Flour was made from the coontie plant’s roots (Florida Center for Instructional Technology, 2002). The Miami River’s resources allowed the Tequesta to trade with the Calusa, Native Americans who lived on the southwest coast of Florida (Historical Society of Palm Beach County, 2009).

Ecological connectivity during in this era served as a baseline in comparison to future eras, as the river was in an original, unaltered state. In its original state, the Miami River stemmed from the Eastern edge of the Everglades. It was fed by groundwater springs, rainwater, overflow from the Everglades especially during the rainy months and consisted of two forks, north and south, in addition to another natural tributary, Wagner Creek (Figure 1.3) (Jackson et al., 1973; Gaby, 1993). The Miami River rapids presented a natural barrier to longitudinal connectivity, albeit a semi-passable one for aquatic organisms, water, and organic matter. If rainfall during the wet season was below average, river flows were substantially reduced, including over the Miami River rapids on the north fork (Gaby, 1993). Laterally, vegetation lined the banks of the river providing breeding grounds and shelter for animals as well as allochthonous material for the river.

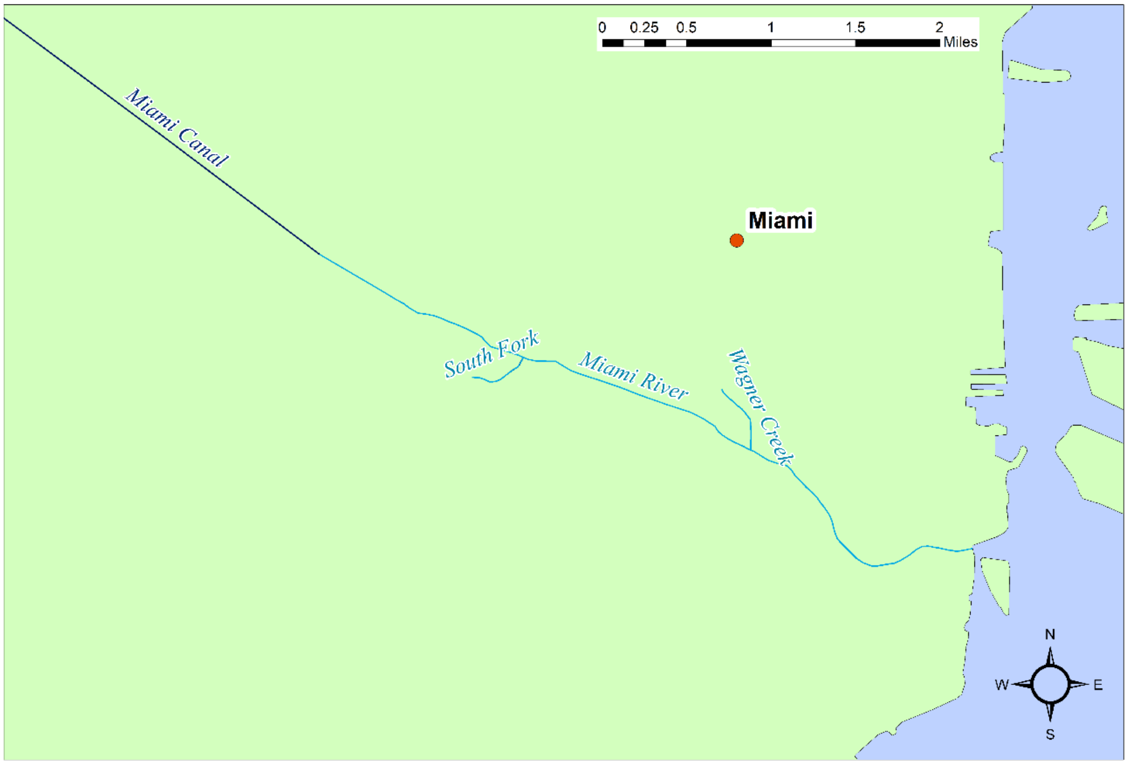

Figure 1.3: The Miami River, its tributary Wagner Creek and the north and south fork connecting to the Miami Canal.

Vertical ecological connectivity was intact as there was no dredging or draining, therefore conditions from the hyporheic zone to the surface were undisturbed. In the river's natural state, any changes to hydrologic connectivity were most likely a consequence of seasonal changes in river flows or tidal cycles, rather than introduced by human activity.

Social connectivity to the Miami River in this era also reflected usage of the river in its natural state. The Tequesta would travel by canoe along the Miami River downstream into the bay or upstream into the Everglades to hunt, gather, and trade with other Native Americans, and thus the river's longitudinal corridor was their major thoroughfare for movement. Canoes were also used to move laterally across the river between the north and south banks where harvesting of plants lining the banks of the river would take place. Considering the vertical dimension of social river connectivity, Tequesta would enter the water to fish, dive, and swim. In this period, there were very limited anthropogenic changes to the river, and the Tequesta depended heavily on the river for life and sustenance.

Era 2: European Arrival to South Florida and the Miami River (1513 to 1816) In the 16th century, the first Europeans arrived at the mouth of the Miami River, permanently altering the lives of the Tequesta and human settlement along the river (Jackson et al., 1973; WLRN, 2015). In July 1513, Juan Ponce De Leon was most likely the first European to set foot on the banks of the Miami River near Biscayne Bay (Gaby, 1993). In 1567, a mission to convert the Tequesta to Christianity was established on the river, where a cross and shelter were built. At first, relations with the Tequesta and Spanish were friendly (Carr, 2012). Trading was eventually established, presumably on the basis of the Spanish giving the Tequesta gifts like rum, weapons like knives, and cloths (Florida Center for Instructional Technology, 2002). However, Spanish soldiers suffered under weather conditions and nuisance from many insects like horseflies and mosquitos, and also harassed the Tequesta (Gaby, 1993). The first Spanish mission along the Miami River ended by 1570. Another mission was attempted in 1743 but also ended unsuccessfully for the Spanish, as the Tequesta were now hostile to the Spanish and were not willing to convert to Christianity. Thus, the mission was abandoned in 1744 (Gaby; 1993; WLRN, 2015; Carr, 2012).

European settlement influenced the Tequesta. Their population declined as a consequence of diseases like smallpox, brought by Europeans, and enslavement by Europeans (Gaby, 1993; City of Miami, 2017). Florida became British territory in 1763 and, potentially out of fear of British enslavement, the remaining Tequesta either fled from South Florida to Cuba or scattered throughout other parts of Florida (Gaby, 1993; Brochu, 2000; National Park Service, 2002). The few descendants of the Tequesta that landed in Cuba mixed with other human populations on the island; those who remained in Florida integrated with Miccosukee and Seminole (Brochu, 2000; Carr, 2012). Little to no Tequesta were left by 1800 and no British settlements were present on the Miami River at that time (Gaby, 1993).

Ecological river connectivity was unlikely to have changed much during this era. Letters from Father Joseph Xavier Alaña, who was sent to establish a mission on the north bank of the Miami River in 1743, showed desire to tame and clear the land for agriculture (Carr, 2012), foreshadowing what was to come in later eras. However, the number and descendants of the human populations that depended on the river changed markedly during this era. The Miami River's banks became a resource for non-native Europeans for transportation to establish missions, and therefore the Europeans' dependence on social longitudinal river connectivity was high. New religions, customs, and items that the Tequesta had not seen previously were now available to them, facilitated by the river's connection to the bay and point of arrival and entry for Europeans. The social connections established with the river and groups of people varied:

the Tequesta depended on the river for sustenance and considered it their home. The arrival of the Europeans could have influenced human-river connections for the Tequesta as strained relations between the two groups could have prevented access to the river where the Europeans settled.

Era 3:Role of the Miami River During the Seminole Wars and Aftermath (1817 to 1869)

The shores of the Miami River may have been empty of human settlements after the Spanish left in 1763, but almost 80 years later the river would be central to wars between Native Americans and settlers. Little to no Tequesta remained in South Florida at the start of this era because of disease and fear of enslavement (City of Miami, 2017). Whereas surviving Tequesta fled to the Caribbean islands or remained in Florida (see Era 2), newly arriving Bahamians and non-Spanish people were encouraged to settle in the area during this era (Gaby, 1993). Once Florida became a territory of the United States through a treaty with Spain in 1821, settlers developed plantations, engaged slave labor, and grew crops such as citrus, palm trees, and pumpkins, and raised livestock like hogs and turkeys (Gaby, 1993). During this era, Florida saw a series of conflicts, termed the Seminole Wars, from 1817 to 1858. The United States Government decided that to end feuds between any white settlers, Creek Indians, and Seminoles, they would murder or forcibly relocate natives west of the Mississippi River to Oklahoma and re-capture runaway or fugitive slaves (Gaby, 1993). These conflicts extended to the Miami River.

This era along the Miami River was marked by warfare on the river and its surrounding area. The Second Seminole War (1835-1842) was one of the bloodiest battles between the United States government and Native Americans, and the Miami

River and Everglades played a central role. Fort Dallas was established in 1838 by the United States government on the north bank of the Miami River as a military base and to prevent the Seminoles, members of the Creek nation from Georgia, from trading with other groups in the Caribbean (Gaby, 1993; George, 1996; Carr, 2012; Dunnavent, 2020). Both Army and Navy soldiers were trained for the environments they would encounter when searching for Native Americans in South Florida. These soldiers were termed "Swamp Sailors" (Buker, 1997), and riverine warfare took place on the Miami River between Native Americans and the United States government. The Navy would patrol the Atlantic coastline and mouths of rivers and combined forces with the army to deploy boats and canoes up the Miami River to follow Native Americans into the Everglades (Dunnavent, 2020). In 1842, the U.S. government decided to withdraw following many casualties of soldiers; most Seminoles retreated into the Everglades and those who remained there became known as the Miccosukee (Gaby, 1993). Other warfare on the river included blockades during the Civil War (1861-1865) where Union blockades on the river isolated settlers. Those who ran the blockades to the Bahamas angered Union members, resulting in burning of settler property (Gaby, 1993). Soldiers involved in the war eventually brought their families to the area, resulting in a growth in population (Ammidown, 1982).

Besides warfare, the Miami River also experienced growth of export agriculture along its banks during this era. Several mills for Coontie, a native plant whose roots were used for making starch, were established around 1840 on Wagner Creek. Another mill was powered by the smaller rapids located on the south fork of the river (Gaby, 1993). Coontie starch was the most important good that was exported during this time (George, 2013). It required a lot of freshwater to process (Gaby, 1993), and was one of the few ways in which people could make a living (Wagner, 1949).

During this era, modifications on the banks of the river were made through human activity, thereby altering lateral connectivity between the Miami River and its floodplains. Many trees were felled on the north bank of the river for the construction of Fort Dallas and extensions of the fort (hospitals, offices, and kitchens). Tree removal increased mobility and visibility for the United States troops against the Native Americans and runaway slaves, and wood was used to fuel boats that carried guns and weapons (Gaby, 1993). Though there was alteration of the banks of the Miami River through infrastructure, longitudinal and vertical connectivity remained relatively unaltered during this era. However, up and downstream travel on the river facilitated riverine warfare as the Miami River was used to transport weapons and access the Everglades. Victims from wars were buried in mounds on the banks of the river. Yet, the Miami River also saw its rapids being harnessed to provide energy for coontie mills, which was an important economic aspect for settlers in this era. Towards the end of this era, the river was being utilized as an economic hub and slowly starting to see growth and change on its banks.

Era 4: The Homesteading Era (1870-1895) Settlers from the northern U.S. and from the Bahamas moved to the shores of the river after the Seminole Wars and were very influential figures in the history of Miami (Jackson et al., 1973; Gaby, 1993). The arrival of these new settlers, often wealthy homesteaders, led to a chain of events that permanently changed the river and South Florida (Shell-Weiss, 2009). For example, Mary and William Brickell moved to the north bank of the river in 1870 (Jackson et al., 1973) and established a trading post with the Seminoles who remained in the area (George, 2013). The stillness of the area appealed to homesteaders like Julia Tuttle. Considered the mother of Miami, she moved to what once was Fort Dallas in 1891 (George, 2013). By 1895, only 9 people lived along the river (George, 2013). Tuttle and the Brickells convinced Henry Flagler, an oil tycoon and investor, to extend his Florida East Coast railway down to the Miami River. Flagler's agreement with Tuttle included 300 acres of land to develop the railroad and a hotel on the north bank of the river, and a promise to "clear the streets, [and] finance a water works" (Jackson et al., 1973; Gaby, 1993). The construction of the railroad led to many workers moving to South Florida and the surrounding area for work the following year.

This era was the last to experience the Miami River in its mainly natural form. Vegetation such as coconut palms, guava, mangoes, and a variety of other citrus plants were planted on the banks of the river by settlers (Jackson et al., 1973; Gaby, 1993). The Miami River's water was clear, springs were still visible, and the river's longitudinal flow and connectivity remained largely unaltered (Jackson et al., 1973). However, lateral ecological connectivity was increasingly altered as more structures were built along the river by settlers, also altering vertical social connectivity by increasing visual access to the river.

Wealthy homesteaders had a large influence on the Miami River's surrounding landscape (Shell-Weiss, 2009). Similar to the original inhabitants of the region, the Tequesta, homesteaders of South Florida also depended heavily on the river. They built their homes on its banks for ease of transportation, trade, freshwater, and fishing. The river also served as the main route to a trading post that the Brickell's established (Jackson et al., 1973). As a trade route, the Miami River also may have mediated improved relationships between Native Americans and settlers, as Native Americans traveled from the Everglades with hides, meats, and coontie starch, among other goods to be exchanged with manufactured goods such as flower and sugar from settler communities (Jackson et al., 1973; George, 2013). The Miami River's aesthetic value was also appreciated by settlers in this era, as evidenced by certain agreements for development. For example, Julia Tuttle gave Henry Flagler land to build a railroad and the Royal Palm Hotel on the condition that her view of the bay was unobstructed (Gaby, 1993), displaying social connectivity. Other social connections to the Miami River included movement up and down the river, which was important relations between white settlers and Native Americans residing further inland and in the Everglades for trade (George, 2013).

Era 5: Incorporation and Early Years of City of Miami (1896 - 1919) In 1896, Miami was officially incorporated as a city. In this era, the area around the river continued to change with increasing human population and infrastructural development. Newly constructed hotels and marinas on the bay attracted affluent people from the northern states, brought in by the new railroad. In the 1880-90s, many Bahamians migrated to Miami to work on the railroad and stayed at Green Tree Inn on the banks of the river (Shell-Weiss, 2009). Bahamian settlers contributed to the growth of Miami and set up vibrant communities in Coconut Grove (Shell-Weiss, 2009). African-Americans and Black Bahamians hired by Flagler cleared pine as they laid down railroad tracks, completing the railroad extension to the north bank of the Miami River in April of 1896. The completion of the railroad marked the beginning of a period of rapid economic and population growth (Jackson et al., 1973;

Shell-Weiss, 2009). For example, in January 1896, Miami had a population of 500 people; by December 1896, it had risen to 2,000 people (Shell-Weiss, 2009).

In addition to being central to the growth of human populations inhabiting South Florida, the Miami River also emerged as a new tourist destination. Guided tours through "wild South Florida" on the *Jungle Queen* boat, the surrounding Everglades, and the rapids of the Miami River attracted outsiders to visit (George, 2013). Musa Isle Village, located on the south bank of the north fork of the Miami River, was a tourist attraction where people went to learn about or experience Seminole and Miccosukee culture (George, 2013). Films were also recorded on the banks of the river, taking advantage of its picturesque scenery that was also appreciated by settlers (George, 2013). Flagler's Royal Palm Hotel's location on the river, fish from the river sold in markets (Shell-Weiss, 2009), and the increasing shipyard business (George, 2013) illustrated further ways that settlers and tourists in South Florida increasingly depended on the river.

As new businesses and new infrastructure were built on the river and its surrounding area, the Miami River became an important socio-economic feature. Its identity changed from one of sustenance for Native American civilizations to one of recreational and economic importance for settlers and increasingly, tourists (Jackson et al., 1973; Shell-Weiss, 2009). Rapid and heavy development, especially dredging, permanently altered the Miami River in this era. Most notably was the construction of the Miami Canal that took place between 1909 and 1913 and connected the Miami River to Lake Okeechobee (see Figures 1.1, 1.2, and 1.3) (Gaby, 1993; Shell-Weiss, 2009; George, 2013). Once the canal was built, a marked decline in water was observed on the rapids in the north fork, evidence of disrupted vertical ecological connectivity (Jackson et al., 1973;

Gaby, 1993; George, 2013). River water was no longer clear, as the canal increased input of sediments from the Everglades into the Miami River (Miami River Commission, n.d.). Construction of the canal also led to removal of plants along the shoreline of the river and created steeper banks, altering lateral connectivity.

Ecological and social connectivity along the Miami River changed markedly during this era in other ways. Longitudinal connectivity increased, in both ecological and social contexts, when the Everglades Land Company dynamited the naturally occurring Miami River Rapids in 1909 to allow for passage of cargo ships through the river and to the port (Shell-Weiss, 2009). The railroad, construction of the canal, and growth of a port near the junction of the Miami River with the Miami Canal all contributed to increasing numbers of people and commerce in Miami, particularly along the Miami River’s north bank (Jackson et al., 1973). Similarly, lateral connectivity, in both ecological and social dimensions, was affected through the construction of the first bridges across the river during this era. For example, the Avenue D Bridge (Figure 1.4), connected the north and south banks of the Miami River and allowed people to walk between the two banks of the river for the first time (George, 2013). Additionally, the Tamiami Canal/ Northwest River Drive Swing Bridge, built in 1921, was built due to population growth westwards into the Everglades area (Florida Department of Transportation, 2012).

Figure 1.4: Avenue D Bridge across the Miami River, circa 1900. Source: State Archives of Florida, Florida Memory.

This era was probably the last to see frequent trading between Native Americans, white settlers, and Black Bahamians as an important aspect of life in South Florida, and one that depended on upstream-downstream travel by canoe and trading on the banks. Major changes to social riverine connectivity with the Miami River, in both longitudinal and lateral dimensions, began in this era and continued in the following eras. This era also marked a shift towards a new kind of vertical social connectivity with the river, manifest in the construction of the Royal Palm Hotel, which added views of the river from higher floors, creating a new visual perspective of the river related to its aesthetic appeal. Interestingly, the hotel was built where archeological artifacts were found and were not carefully relocated; they were eventual largely destroyed by construction of a commercial high-rise building (Carr, 2012). This action, combined with other major changes on the river like the removal of natural rapids and the construction of the Miami Canal reflected a defining aspect of this era: increasing erasure and transformation of the ecological and social riverscapes of the past in favor of built environments, future commerce, and more distant human-river interactions.

Era 6: Growth and Industrialization (1920-1959) Miami experienced economic and population growth in the 1920s, with accompanying transformations along the Miami River. For example, the river was dredged and widened to allow passage for larger vessels upstream to the port near the start of the Miami Canal (Gaby, 1993). During the Prohibition era in the 1920s, the river was used for smuggling alcohol from the Caribbean, with drop-off points in the river resulting in increased crime on its waters and banks (Cooke, 2016). Despite crime, businesses on the river were doing well financially, including those of Bahamian immigrants who moved to Miami in the early 1900s (George, 2013). However, a hurricane in 1926 resulted in high damage to infrastructure on the river including the Royal Palm Hotel (Gaby, 1993; George, 2013). The hotel was bulldozed in the 1930s and its marina was filled in, narrowing the mouth of the river (Gaby, 1993). Despite this, the continued heavy usage of the river, population, and real estate growth and the eventual construction of Brickell Avenue Bridge which increased bank to bank access in 1929 (George, 2013).

Through the 1930s and 1940s, the river continued to see human population growth and rapidly degrading water quality. Diesel exhaust (George, 2013) and oil spills (Gaby, 1993) were seen on the Miami River during this era. Trash, tires, sunken boats, and boat parts were also becoming frequent sightings on the river as boat production for World War II took place on the banks of the river (George, 2013). After World War II, many people decided to stay in Miami because of its warm climate (George, 2013). Meanwhile, problems with the river’s quality persisted and worsened. In 1949-1950, the

Miami River had 41 raw sewer pipes emptying into the bay and 21 emptying into the river with trash in its waters (Jackson et al., 1973; Gaby, 1993).

Pollutants made their way into the Miami River through construction of roads and bridges. Before channelization, flow from the Everglades and elevation differences seasonally altered flow and helped flush out pollution. However, events such as the construction of the Miami Canal, population growth, sewage pipe installations, and improper disposal of industrial materials, the river's health worsened.

Disruptions to ecological connectivity impacted the way in which people interacted on the social dimension. People began to adapt to new activities and uses of the river but still relied on the river for fishing and for transportation. Regardless of heavy pollution and industrialization of the river, people used the river for recreational activities such as swimming, which according to Gaby (1993), there were no reports of people getting sick. Some interactions were lost, such as obtaining fresh water from the river to drink, while others were gained like easier transportation and navigation. Pollution was a major issue during this era because of growth and commerce, ultimately impacting river connectivity.

Era 7: Rise of an International City: Crime and Restoration (1960 - 1999) As the city's skyline began to emerge, Miami was becoming an international city as many sought refuge from oppressive governments. Fidel Castro came to power in Cuba in 1959 and during the 1980s, thousands fled to Miami where many stayed in Tent City, located on the banks of the Miami River, that harbored hundreds of immigrants called the *Marielitos* (George, 2013; Santiago, 2021). Miami saw itself in the center of race riots due to the killing of a Black motorcyclist, Arthur Mcduffie, in 1979 and tensions because of disparities between the Black and the increasing immigrant community (George, 1996; Santiago, 2021). The mass exodus of Cubans in 1980, termed the Mariel Boatlift, and the and race riots led to the need of more police officers being hired. There was a reduction in officer quality and integrity as police officers who would not normally be hired were inducted into the police force, resulting in corruption (Lassiter, 1987). A new Port of Miami, today's port, played a role in smuggling (Gaby, 1993; George, 2013) as its opening in 1960 led to the river seeing illicit activities like drug smuggling and crime in its waters (Shell-Weiss, 2009; Miami Herald, 2015; Liff, 1985). The Miami River Cops scandal in the 1970-1980 was a result of corrupt police officers becoming involved in smuggling cocaine and resulted in coast guard chases on the river, illegal dumping of drugs, and killings on the river (Jackson et al., 1993; Gaby, 1993; Cohen, 2015; NBC News, 2020; Liff, 1985).

As crime on the river grew, suburban areas also grew and downtown development decreased, distancing Miamians from the river (George, 2013). Less attention was given to the river as it had now become a working river laden with crime (George, 2013). Zoning and development around the river took place (Shell-Weiss, 2009). In the 1960's, the construction of the highway system across the Miami River led to the decline and displacement of half of Historic Overtown's population (George, 1996; Overtown Rising Land & People, n.d.). This resulted in the large displacement of African-Americans as Overtown was a predominantly Black neighborhood that, due to segregation laws, housed Black workers who moved to Miami to work for Flagler from the Caribbean islands such as the Bahamas and Cuba during Era 4 (Overtown Rising Land & People, n.d). The river's degrading quality in previous years resulted in people to rally for the cleanup and restoration of the Miami River in the 1960s (Gaby, 1993). Because of the construction of the port in the 1960s, boat yards stood on the north bank of the river as boat traffic negatively impacted the river and organisms living in it. Life in the river included those that could adapt to polluted conditions (Jackson et al., 1993; George, 2013). In the 1970s, citizens, local and state leaders, investigated the neglect of the river and enforcement codes (Gaby, 1993). Despite crime, in the mid-1970s, a Riverwalk was developed that attracted people from the suburbs back to the city, yet interest regarding the river disappeared again by the 1980s although it still provided jobs (George, 2013). Through the 1980s, a coordinating committee formed as a watchdog organization for the river, yet progress was deemed too slow by two grand juries in 1991 and 1998. Thus, the Miami River Commission was created in 1998 (Miami River Commission, 2001).

During this era, the river was no longer considered a life source but instead an industrial and commercial hub, reflecting the activities that were ongoing in its city. The river became an important aspect for international trade as the marine industry continued to affect river's quality (Jackson et al., 1973; George, 2013). An influx of Latin American migration to Miami resulted in the city to be deemed the Gateway to the Americas (George, 2013). The real-estate boom of the 1990s in South Florida began with riverfront influences along with immigrants from Cuba and ongoing heavy development downtown (George, 2013). Buildings that are seen in today's era began to appear on the banks of the river in Downtown Miami (George, 2013).

Increased longitudinal connectivity led to illegal substances being brought into Miami, and the river quickly gained the reputation of a polluted system where shootings and drug smuggling took place (Lassiter, 1987). Social connectivity shifted interactions concerned with the industrial usage of the river such as construction of bridges which disrupted longitudinal ecological connectivity by potentially impacting flow and impairing movement of fauna in the river. Despite disrupted connectivity, influence from Caribbean migration was seen through religious practices as the Miami River was used as a place for animal sacrifices and other offerings like fruits and objects. Connectivity around the river kept increasing because of the construction of the Riverwalk, additional businesses, and the metro-mover in 1994 (George, 2013). More buildings were constructed, and the skyline of Miami began to take shape.

Era 8: Restoration Meets Glamour on the Miami River: Modern Day Miami (2000 – Present) Presently, the Miami River is a fully mixed-use, urban, working river, completely unrecognizable from the original river (George, 2013). To protect the river from further degradation of past eras, the Florida legislature created the Miami River Improvement Act in 2000 (Miami River Commission, 2001). According to the Miami River Commission, the river is categorized into zones: the upper river is characterized as an industrial and shipping zone, the middle river is defined by its residential, recreational and industrial zone, while the lower river is the high-density urban area zone (Figure 1.5) (Miami River Commission, 2001). Commercial districts, high-rise luxury apartments, parks, and restaurants to shipyards demonstrate the diversity of activities on the river, but also the stratification of social classes and sectors that emerged from this era. Physical access to the waterfront can vary through the zones as construction, private neighborhoods, and industrial businesses block access to the river front. The Miami River Greenway construction began in 2001, where informative signs and landmarks, trash cans, benches, beautification projects such as parks, and drainage improvements are being added along the shoreline.

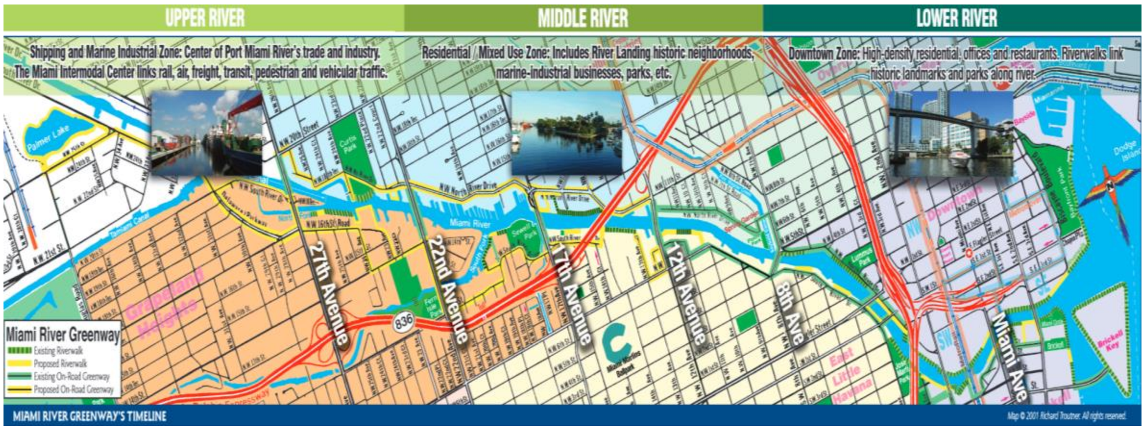

Figure 1.5: Miami River Zones categorized into three zones: upp*er, middle, and lower. Source: Miami River Commission.*

Today, the Miami River landscape varies depending on the zone. Benches are present on walkways so that people can sit and interact by river in the lower zone while the middle is residential areas, in contrast to the upper river shipyard landscape. Connections to past eras can be found including a statue of a Tequesta and Julia Tuttle (George, 2013) in addition to the Miami Circle discovered in 1998 that is evidence of a Tequesta chief home or temple (Brochu, 2000; Carr, 2012). Informational signage along the Riverwalk are in various languages about how the river helped shape the city as a gateway to the Americas through the opening of ports and trade on the river (George, 2013). Businesses such as fish markets and restaurants, boat yards, and individual sellers catching fish and selling it to restaurants can also be seen. Boathouses are also much less common, although there is still an issue of sunken boats in the river as previous eras.

Since the 2000s, the river's atmosphere changed, and its reputation and quality improved (Miami River Commission Report, 2002, 2020; personal communication with boat captain, City of Miami employee; Rodriguez, 2020), although issues such as drug smuggling remain (NBC, 2020). Restoration efforts of the Miami River Commission improved the river's health and aesthetics are as well with the construction of the Riverwalk (Miami River Commission Report, 2002, 2020; personal communication with boat captain and Miami River Commission employee) and the hosting of Miami Riverday Festival (Greater Miami Convention & Visitors Bureau, 2021). Restoration efforts like those of the Scavenger Boat 2000 and the Miami River Commission are resulting in fish coming back to the river as quality is improving and becoming more hospitable for fish like snook, tarpon and every couple of years a crocodile and dolphins can be seen on the river (personal communication with boat captain; DERM employee; City of Miami employee, two local residents). Marine debris is a problem as single use plastics make their way to the river including plastic bags which are particularly a problem for boats as they become lodged in the propellers and impair navigation (personal communication with boat captain). The Scavenger Boat 2000, contracted by the City of Miami in 2003, oxygenates the river and collects debris along the longitudinal dimension, improving the appearance of the river while reducing pollution and improving its quality (Uchiyama, 2006). The improved profile of the river is resulting in higher real estate prices that changing the socio-economic landscape of river as accessibility to lower income people is decreasing. Affluent non-residents purchase real estate on the river as tourist recreate on party yachts on the river, a contrast to a time when people would tour the river for its wilderness in previous eras.

Much vegetation was removed from the banks of the river, with few mangroves lining the bank in areas of the river. Vertical connectivity was impacted when the river was dredged and deepened. Dioxin presence in the Wagner Creek riverbed resulted in the river to be dredged to remove the contaminated sediments (Miami Herald, 2017). The change the river has undergone depicts how connectivity can change quickly because of anthropogenic factors, turning a wild pristine river into one that is heavily urbanized and controlled.

Connectivity continues to change on the social dimension as new activities appear on the river with reconstruction of bridges, buildings, and the Riverwalk as the city's core is revitalized. People kayak along the river as large cargo and recreational boats make their way up and downstream. When large boats travel on the river, bridges must go up, temporarily disrupting traffic. People fish under these bridges for recreation as well as livelihood. Vertical connectivity is also present through the interaction of many high-rise buildings on the river, many of which have rooftop pools, places to play sports, and lounging areas with the Miami River and buildings on its banks as a backdrop.

Figure 1.6: Avenue D Bridge Across the Miami River, 2015. Source: State Archives of Florida

1.5 CONCLUSION

This study examines change over time in the Miami River, in Florida, United States through the 1500s to 2020 using river connectivity as an analytical lens. Ecological change and social relationships were identified by major historical events involving the river. Until now, the Miami River's history has not been analyzed through the framework of river connectivity, ecologically nor socially. Limitations and assumptions of this study include the subjective divisions of eras. Although they were divided into major events revolving the river, it could have been divided by different events. Secondary information was relied upon for account of historical events. More interviews could have been conducted, specifically for the last two eras for additional primary sources.

Nevertheless, this analysis has helped identify lessons from the past and visions of the future for the Miami River. Through the river's history (Figures 1.7 and 1.8) we see how anthropogenic changes can impact ecological connectivity and how ecological factors can influence social connectivity. Historical analysis illustrates the link between social and ecological aspects. It can also help understand why certain changes took place and what society valued and prioritized at the time by highlighting long term issues, like infrastructure, and similarities, such as continued dredging, throughout eras. Through the analysis of the past and the changes imposed on the river, we can ask what could have been done differently to enhance social connectivity but also minimize disruption of ecological connectivity, coupling social and ecological factors.

As the river's ecosystem services became less valued new ways of interacting with the river on the spatial dimension emerged. These interactions between social and ecological processes demonstrate that the river is a social ecological system (Dunham et al., 2018). For management and restoration to be successful, both social and ecological dimensions should be taken into consideration. The integration of social and ecological connectivity can be used to predict changes in river stability and analyze access to rivers. Understanding rivers as social-ecological systems through a connectivity framework can allow for more comprehensive restoration and management efforts by incorporating the needs of the community and actions that would improve and protect the river's health.

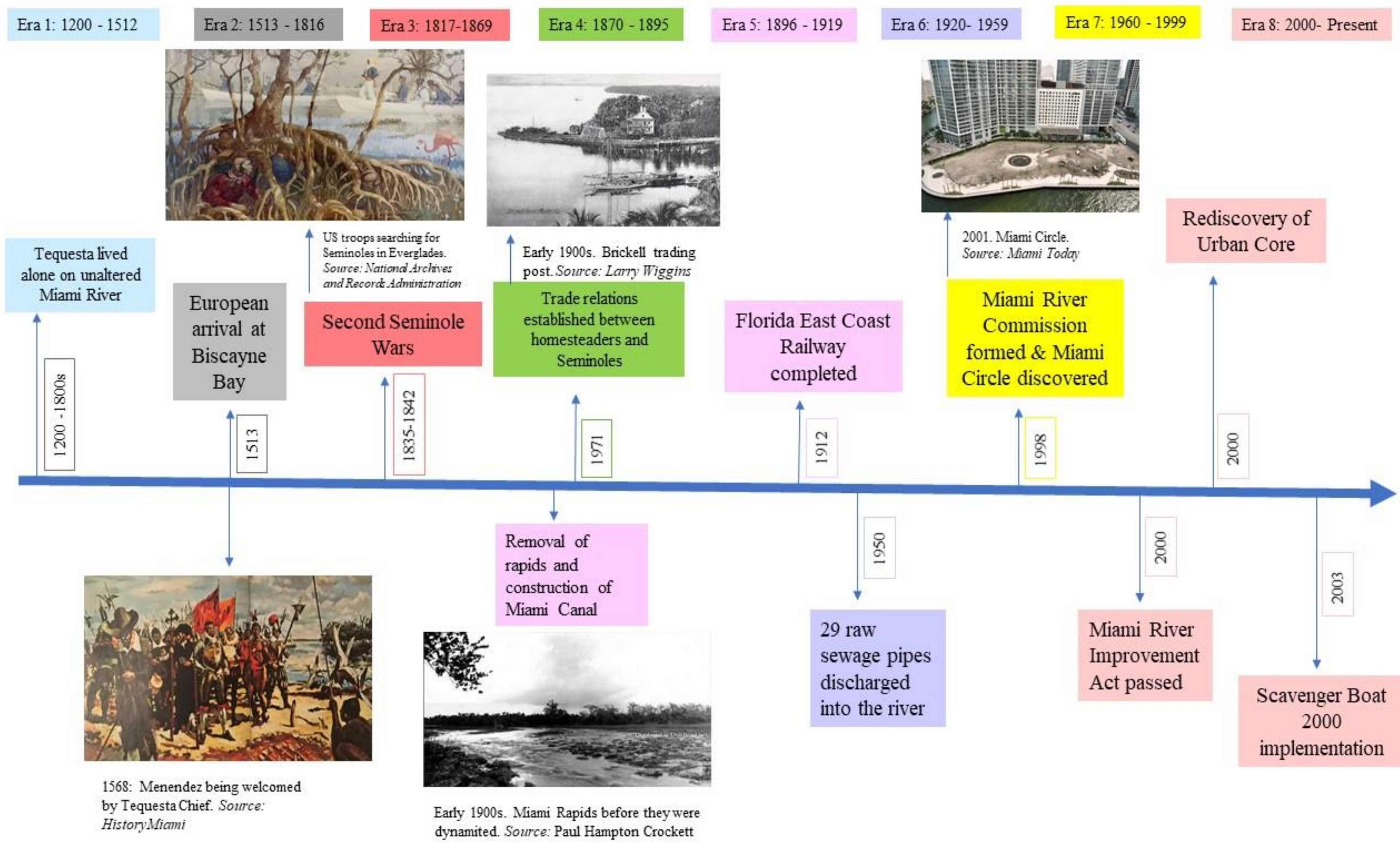

Figure 1.7: Social-Ecological timeline of the Miami River.

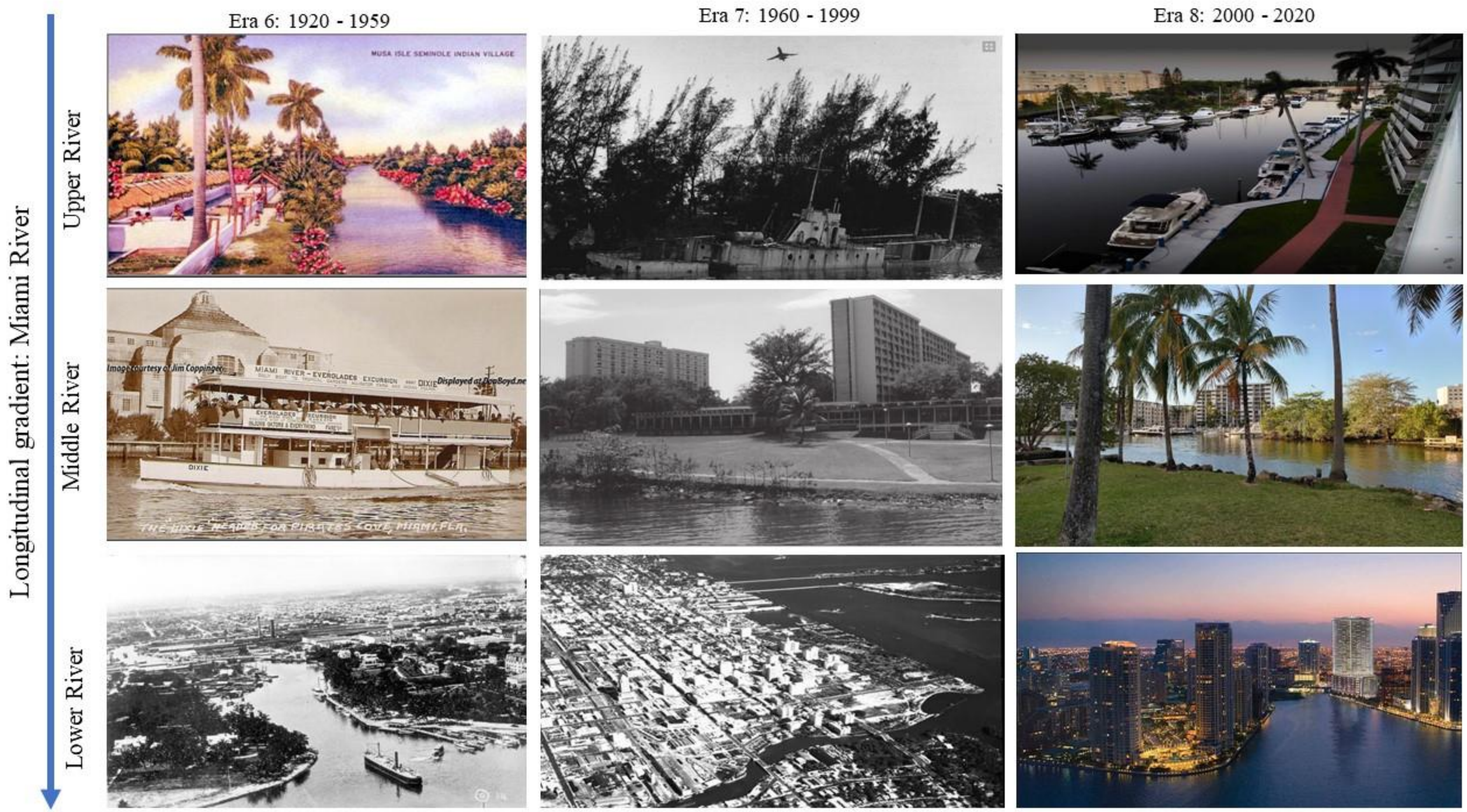

Figure 1.8: Pictures of changing connectivity along the urban gradient during the last 100 years.

Upper River left to right: Picture 1: Musa Isle Village on the Miami River on 27th Avenue, 1940. *Florida State Archives* Picture 2: Sinking freight boat on south side of Miami River behind junk car yard on 35th Ave, 1982. *Bob East/Miami Herald Staff* Picture 3: Miami river residencies on 27th Avenue, ~2020. *Eduardo Nunez/Google Images* | Middle river left to right: Picture 1: Pirate's Cove (Coppinger's Tropical Garden), 1920. *Jim Coppinger* Picture 2: Retirement facilities on the river,1960s Elliot Salloway. *Along the Miami River* Picture 3: Sewell Park, ~2020.

Amusements and Parks| Lower river left to right: Picture 1: Mouth of river, 1922. *Florida Memory* Picture 2: Downtown Miami and the River, 1947. *Florida Memory*. Picture 3: Mouth of Miami River emptying into Biscayne Bay, Late 2010s. *Miami River Art Fair*.

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CHAPTER 2

SPATIAL AND TEMPORAL TRENDS IN WATER QUALITY ALONG THE MIAMI RIVER, FLORIDA, USA

2.1 ABSTRACT

The Miami River is a mixed-use ecosystem in a densely populated city. Significant urban development took place in Miami over the past 40 years. The Miami River is a natural laboratory for exploring social and ecological changes in urban rivers and their water quality, as it is the center of development for Miami, which emerged in large part because of the important socio-economic and ecological services the river provided to a growing human population. This study examined water quality change over time along an urban spatial gradient, asking (1) has water quality changed along the urban gradient of the Miami River between 1984 and 2019 and (2) what are the different types of solid waste and debris in the river? The data show that the quality of the Miami River generally improved over the past 40 years. Urban rivers continue to be understudied ecosystems and require further research. Although an increase in available literature and focus on urban rivers has been ongoing, there is still a lack of literature on the heavily urbanized Miami River. This study fills these gaps by applying a mixed methods approach and integrating quantitative long term water quality data and qualitative data through observation of debris and interviews.

Key words: Urban rivers, urban ecology, river debris, water quality, long-term trend analysis

2.2 INTRODUCTION

There has been an increase in research and restoration efforts in urban rivers in the past 25 years. Publications like those from Paul and Meyer (2001), Walsh et al. (2005), and Francis (2012, 2014) have led to urban rivers being recognized as novel ecosystems with identifiable characteristics caused by urbanization, known as an Urban Stream Syndrome (USS; Walsh et al., 2005). USS affects river water chemistry as a consequence of increased nutrient loading and affects physical / geomorphologic characteristics of rivers through actions like dredging for navigation purposes (Walsh et al., 2005). In the field of urban ecology, there is a growing interest in human and social dimensions of ecosystem services in urban settings (Wu, 2014), and this interest extends to urban rivers (Durham et al. 2018). For example, a recently introduced concept, *ecology for cities*, examines urban settings as social-ecological systems and aims to move towards sustainable, more resilient, and equitable uses of resources in urban settings (McHale et al., 2015; Pickett et al., 2016). To achieve ecology for the city, we must be able to fully understand drivers and symptoms of USS.

One way that the impact of urbanization on rivers can be seen temporally is through changes in water quality. Temporal changes can be seen attributed to urbanization in the amount of dissolved oxygen, for instance, in a lotic system (Paul and Meyer, 2001). Temperatures are generally higher in urban rivers because of heat islands, where urban areas store and retain heat (EPA, 2021). Additionally, removal of plant cover (and therefore shade), and heated stormwater runoff from impervious surfaces can attribute to higher temperatures in rivers (EPA, 2021). Oxygen levels can be impacted by the temperature of water: oxygen solubility is lower in warmer water, thus decreasing the amount of oxygen available to the aquatic ecosystem (Wetzel, 2001). Temperature also influences which species are present in the stream, as some species require higher amounts of dissolved oxygen than others (Somers et al., 2013). Additionally, nutrients have shown to be positively correlated with urbanization (Halstead et al., 2014). Total nitrogen and total phosphorus are the nutrients attributed to a decrease in urban stream quality and have urban sources like pet waste, fertilizer application and runoff, and sewage and septic tank leaks (Paul and Meyer, 2005; Halstead et al., 2014). Over time, as a river becomes urbanized, these water quality metrics respond and shift to reflect anthropogenic changes. For instance, stormwater that drains into rivers may carry waters that contain nutrients derived from fertilizer application from homes or from agriculture. This would result in higher levels of phosphorus and nitrogen in rivers. Chemical analysis of these parameters can indicate factors impacting the quality of the river (stressors). Using this information, regulators can impose restrictions or limit activities on the river through setting policies and enforcement, which impacts the usage of the river. Continued quality assessment can assist in determining if restoration efforts are successful (Sierra Stream Institute, 2021).

Urban rivers frequently have degraded water quality and can pose risks for human health (Rice, 2012). Yet for some people, urban rivers are the only exposure to nature, or an ecological system, that they are familiar with or interact with daily (Francis, 2014). Ecological conditions are linked with social and cultural importance of urban lotic ecosystems (Francis, 2014). Urban rivers act as a way to connect people to nature and tell the story of a city (May, 2006). In addition, they also create spaces where people of many different socioeconomic classes and backgrounds meet each other (May, 2006).

This is the case with the Miami River, as it is a place where many different types of people and businesses mix, a reflection of the City of Miami. However, debris in the river, which acts as a corridor for trash to Biscayne Bay, can impede recreating near or on the urbanized river. Debris pollution can also harm organisms living in the river through ingestion or entanglement, cause blockages in storm drains, and can be an issue to boat propellers (Emmerik and Schwartz, 2019). It is therefore important to incorporate visible factors of water quality, such as debris, when assessing river health.

The Miami River is a mixed-use ecosystem with which people from different socio-economic backgrounds interact, and where businesses range from family owned to large commercial entities in a densely populated city. In addition to economic importance, the river provides important habitat to aquatic species like the Florida manatee (*Trichechus manatus latirostris),* jackfish (*Caranx hippos),* mullet *(Mugil cephalus),* and occasional crocodiles and dolphins (personal communication with City of Miami employee; Miami River commission, 2021). Significant urban development took place in Miami over the past 40 years. The banks of the Miami River saw growth in infrastructure (see Chapter 1), especially in high rise residential buildings (George, 2013). Additionally, the city witnessed significant human population growth (from 1,625,509 in 1980 to 2,701,767 in 2020 (Office of Economic and Demographic Research, 2017; United States Census Bureau, 2021), shifting racial demographics, fast-paced construction, environmental movements and restoration, and gentrification (George, 2013). The Miami River has been subjected to many changes as the city was increasingly urbanized, and these changes may have negatively affected social concern for river integrity (Francis, 2014) and contributed to a decline in water quality beginning in the

1900s in the river. The Miami River is thus a natural laboratory for exploring changes in urban rivers and their water quality over time, because of the important social-economic and ecological services this river provides to the growing human population (Gurnell et al., 2007). Through all these changes, the city has witnessed a rediscovery of its core, where the Miami River is located (Rodriguez, 2020).

Although an increase in available literature and focus on urban rivers have been occurring, there is still a lack of literature on the heavily urbanized Miami River. There is also no literature to date analyzing long-term water quality trends in the Miami River temporally or spatially. This study examined water quality change over time across an urban gradient in the Miami River from its original source to where it flows into Biscayne Bay in South Florida, USA. I asked two main questions. First, has water quality changed along the urban gradient of the Miami River between 1984 and 2019? This question allows for quantitatively measuring USS symptoms in the Miami River attributed to the growth of the City of Miami. This is reflected in its geomorphology, particularly its channelization, dredging, and hardening and development of its banks, and water chemistry. Second, to incorporate qualitative methods, what are the different types of solid waste and debris in the river? This adds a social-ecological component as it is another manner in which rivers are impacted anthropogenically.

2.3 METHODS

The Miami River is located in South Florida and, in its original extent, spanned 7.2 kilometers in length before flowing into Biscayne Bay (Jackson and Conlon, 1973; George, 2013). Prior to the construction of the Miami Canal, its main sources of water were springs and overflow from the Everglades, with rapids located on the north fork (Gaby, 1993). In 1909, construction of the Miami Canal began, and the rapids were dynamited to make navigation possible. The Miami Canal was completed in 1913, with a distance of around 112.65 kilometers, and its construction effectively connected the Miami River to Lake Okeechobee, its new main source of inflow.

To examine spatial and temporal trends in water quality of the Miami River, I obtained water quality data from the Miami-Dade County Department of Environmental Regulation and Management (DERM) from 1978 to 2020, which correlate temporally with the last two eras (7 and 8) described in Chapter 1. Water samples were collected from seven sites along the river ranging from Miami River sampling site MR07, the most upstream site, to Miami River sampling site MR01 where the river meets the bay as the most downstream site (Figure 2.1). The sampled area of the Miami River is categorized into zones. These include industrial, commercial, and residential zones divided into upper, middle, and lower river, respectively (Miami River Commission, n.d.). Total phosphorus, nitrate and nitrite, dissolved oxygen, specific conductivity, temperature, total coliform, and fecal coliform were the parameters sampled.

The sampling points where parameters were measured were: MR01, MR02, MR03, MR04, MR05, MR06, and MR07 (see Figure 2.1and Table 2-1). MR01 and MR02 are in the lower river, MR03 in the transition zone between lower and middle, MR04 and MR05 are located in the middle river, and MR06 and MR07 are located in the upper river. The lower river is characterized by a high-density urban area (commercial, residential) and landmarks, the middle river characterized by residential, mixed use (marine industrial businesses, parks), and historic neighborhoods, and the upper river is used primarily by the shipping and marine industry (see Figure 1.5 from Chapter 1). Considering these zones allows exploration of links between activities in certain

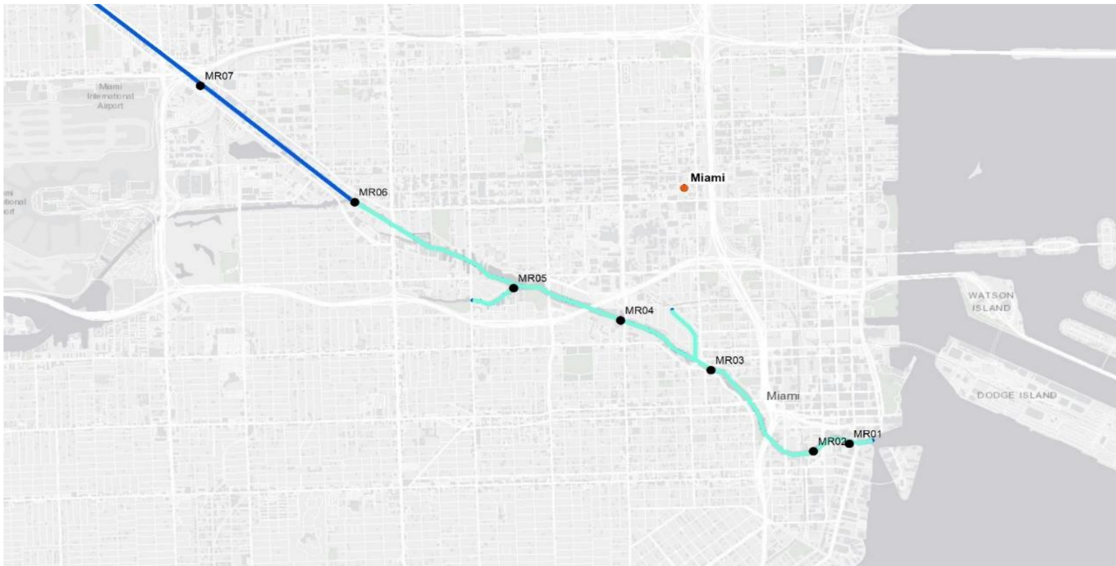

Figure 2.1: Map of sampling sites along the Miami River ranging from MR01 (most downstream site near the bay) to MR07 (most upstream on Miami Canal). Source: ArcGIS, collection sites from DERM.

sectors and their relation to river health through the examination of water quality data. Closer to the bay, there is more tourism and more high-end infrastructure like luxury hotels and condominiums, in contrast to more upstream sites, closer to the Miami Canal, which are more industrial. There are also fewer landscaping plants, riparian vegetation, and mangroves in the more industrial zones of the river upstream. A natural (rather than urban) spatial gradient exists as well, as the river becomes more saline downstream and closer to the bay. Water quality data was collected once a month over a period of 1978-2020 across the aforementioned seven sites in the Miami River. Parameters measured were total phosphorus, nitrate and nitrite, dissolved oxygen, specific conductivity, temperature, fecal coliform, and total coliform. The data provided by DERM is an extensive dataset with thousands of data points per parameter. Thresholds for water quality were based on county and federal levels.

Table 2-1: Sampling points along the river, with MR01 being the most downstream site and MR07 as the most upstream site. Source: South Florida Water Management District, DBHydro.

Site	Location
MR01	Biscayne Blvd/Sw 3 St. Mouth of the Miami River at Green Marker 3
MR02	Sw 2 Ave/Sw 4 St. Miami River 30 Meters Upstream Nw 2 Ave. Bridge
MR03	Nw 7 Ave/Nw 6 St. Miami River Between Wagner Creek and 5 St. Bridge
MR04	Nw 12 Ave/Nw 10 St. Miami River 30 Meters Upstream of Nw 12 Ave. Bridge
MR05	Nw 19^{th} Ave/Nw 14 St. Miami River Downstream Mouth of Comfort Canal (C-5)
MR06	Nw 30 Ave/Nw 20 St. Miami River Downstream Mouth of Tamiami Canal (C-4)
MR07	NW 39^{th} Ave/Nw 36 St. Miami River Downstream Salinity Control (S-26)

The standards (or criteria/thresholds) are as follows: 4 mg/L for dissolved oxygen (county standards), 0.04 mg/L for total phosphorus (EPA standards), 1000 Colony Forming Units (CFU) for total coliform (county standards), and 0 CFU/100 ml for fecal coliform (county standards). For these graphs, lines were added to the cumulative sums and scatter plots in order to see if recorded values exceeded the standards. Nitrogen levels did not exceed the EPA standard at 1 mg/L, temperature does not have a standard, and specific conductivity has natural variability due to marine influences and therefore difficult to set a standard for it.

The Cumulative Sums (Cusums) method (Regier et al., 2019) was used for analysis of the timeseries water quality data to examine potential presence of temporal trends in the data. The cumulative sum is calculated in the following way: the mean of all values is subtracted from each value. The difference is then divided by the standard deviation, and these values give the cumulative sum (see equations below).

$$z_i = (x_i - m)/\sigma$$

In this equation above , the data is being standardized, where z_i represents the standardized data, where x_i is the values of the parameters from the dataset, m is the dataset mean, and σ represent the standard deviation of the data set.

$$z_{is} = z_i + z_{is}-1$$

In this equation above, the cumulative sum of the standard values is determined. z_i are the standardized values of the dataset. Here the standardized values are being added to determine the cumulative sums.

Values of the selected parameters were examined through this statistical framework to distinguish below average, average, or above average values. The statistical program R was used to calculate these values and visualizations were produced using ggplot2 (R Core Team 2016). Scatter plots were used to visualize spatial trends in the data. Data were separated by water quality parameter and by site, where the X-axis was the year and the Y-axis represented parameter units. Data was averaged to one point per year. The R package used to create visualizations was ggplot2.

Generalized linear models (GLMs) were used to determine which factors (site or year) had more of an impact on water quality parameter value. These models indicate the relative importance of site and year for determining water quality values. Akaike Information Criterion (AIC) scores were compared to quantitatively determine which, if any, factor was more important. The R packages used were glmmADMB, and glmmTMB.

In addition to the water quality data for the Miami River from DERM, this study also examined coarse debris (i.e., garbage in the river) as an additional component of water quality and river condition. Data was provided by the City of Miami for years 2017 – 2021 on daily data on trash collected in the river by the Scavenger Boat 2000.

Additionally, observations were made on river debris through two walking reconnaissance trips along the river (2019, 2021) and two kayak trips (2021). Incorporating debris data added a human dimension to this study, and people who work on the river and interact with it daily were selected for interviews. To expand on the human dimension aspect and perspectives on the river's current state, I conducted six interviews (IRB-20-0571), disaggregated as employees of the City of Miami (1), Miami River Commission (1), DERM (1), boat captains (2), and archeologist (1). Interview questions ranged from what types of changes participants have seen in the river to how they view the river (See Appendix Guiding Questions for Interviews).

2.4 RESULTS

Temporal trends over past 40 years show an improvement in water quality

There was a general improvement in water quality in the Miami River from the 1980s to present day (2019), although there were occasional spikes throughout that time. For the cumulative sums analysis, data from all sites were analyzed per parameter. Total phosphorus was recorded in low values until the mid-1980s, at which time phosphorus concentrations began and continued to occur in above average levels until the mid-1990s, exceeding the standards for total phosphorus (Figure 2.2). From the mid-1990s to present, phosphorus generally occurred in the Miami River at below average levels, except for occasional pollution events that exceeded the standards. Nitrate and nitrite appeared in low concentrations until spikes began in the mid-1980s (Figure 2.3), but no values exceeded NOx standards. From the beginning of the 1990s until 2015, the Miami River experienced above average nitrogen levels based on cumulative sums analysis. After 2015, we started to observe below average nitrogen levels. Dissolved oxygen levels were generally below average the Miami River from the 1980s to early 2000s, then began to increase, a trend continuing to present day (Appendix Figure A-1). Fecal coliform, always exceeding the standard, had above average values during the 1980s to mid-1990s (Appendix Figure A-2). Two spikes were present in the river in the late 1990s and late 2000s. Concentrations began to occur at below average levels in the mid-1990s and the

Figure 2.2: For total phosphorus, Box A depicts the values of total phosphorus in the Miami River across all sites and the black line is the EPA standard at 0.04 mg/L. Box B shows standardized values, where phosphorous values across all sites where subtracted by the average of the data set for phosphorus and divided by the standard deviation while Box C shows cumulative sums of the standardized values, showing shifts in the data as it moves below or above average. Values above average are depicted in red and below average values are depicted in blue.

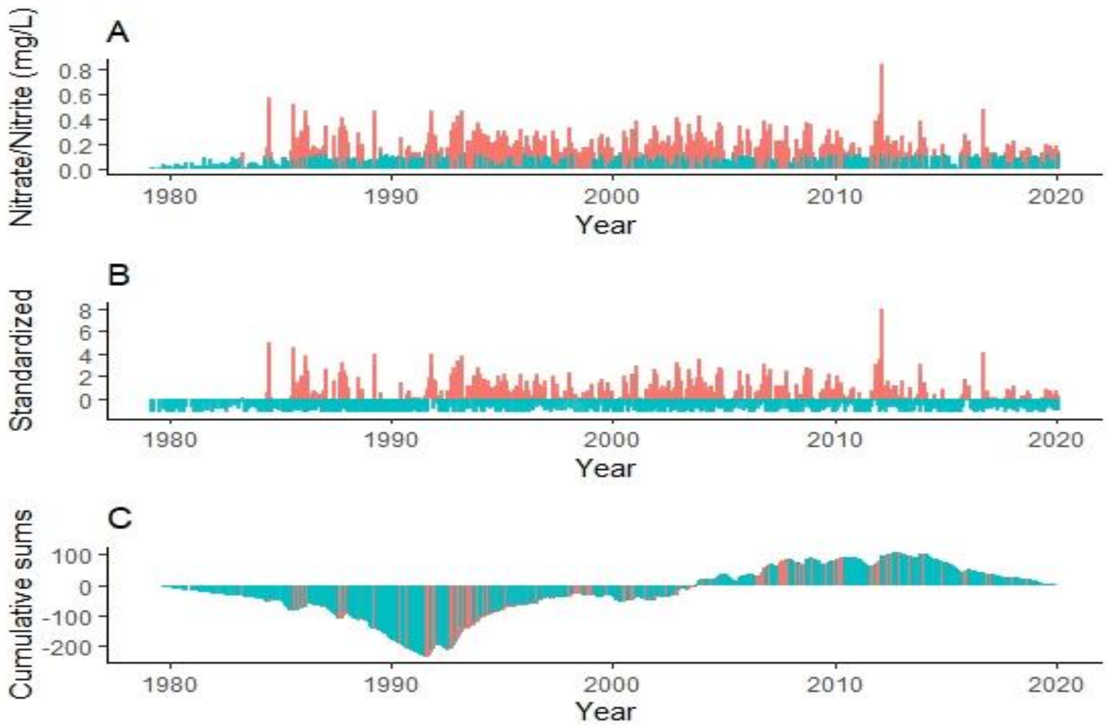

Figure *2*.3: For nitrate and nitrite (NOx), Box A depicts the values of nitrogen in the Miami River across all sites. The standard, 1 mg/L, is not shown as NOx values are below the value and do not exceed it. Box B shows standardized values, where nitrogen values across all sites were subtracted by the average of the data set for nitrogen and divided by the standard deviation while Box C shows cumulative sums of the standardized values, showing shifts in the data as it moves below or above average. Values above average are depicted in red and below average values are depicted in blue.

trend continued to present day. Total coliform levels in the Miami River spiked frequently throughout the mid-1980s and mid-1990s but spikes started to become much less frequent in the mid-1990s, although the standard was always exceeded (Appendix Figure A-3). Neither specific conductivity nor temperature have clearly interpretable trends over time and were thus not included in this analysis. Although parameters like dissolved oxygen and total phosphorus always exceed the standard in the cumulative sums graphs for all sites, scatter plots used to visualize spatial trends are more telling of which sites exceeded the standard.

Spatial trends show that water quality varies throughout the Miami River

The longitudinal gradient of the Miami River that was sampled showed trends in water quality for several parameters. Using scatter plots, I visualized the following results. For phosphorus, the mouth of the river (MR01) showed the lowest values, while the most upstream sites (MR06 and MR07) had the highest values, exceeding the standard during the late 1980s until the mid-1990s (Appendix Figure A-4). There was a trend over time that showed a decrease in phosphorus, which was consistent with the cumulative sums analysis. For nitrate and nitrite values, which do not exceed the standard, the mouth of the river (MR01) and most upstream site (MR07) exhibited consistently lower concentrations (Appendix Figure A-5). The sites located spatially in between MR01 and MR07 consistently exhibited higher values for nitrate and nitrite. Although spikes were apparent in this data as well as the cumulative sums analysis, there was much less support for any consistent trends over time when the sites were examined separately. Dissolved oxygen was highest at the mouth of the river (MR01), and consistently declined along the spatial gradient as one moved upstream (Figure 2.4). There was also a positive trend that supported the cumulative sums analysis that showed a temporal trend. Sites MR01 and MR02 consistently exceeded the standard while MR03 and MR04 also exceeded the standard during 1990 and then again beginning in the 2000s. MR06, only surpassing the standard once in 2010, and MR07 did not exceed the standard but have increased dissolved oxygen levels over time.

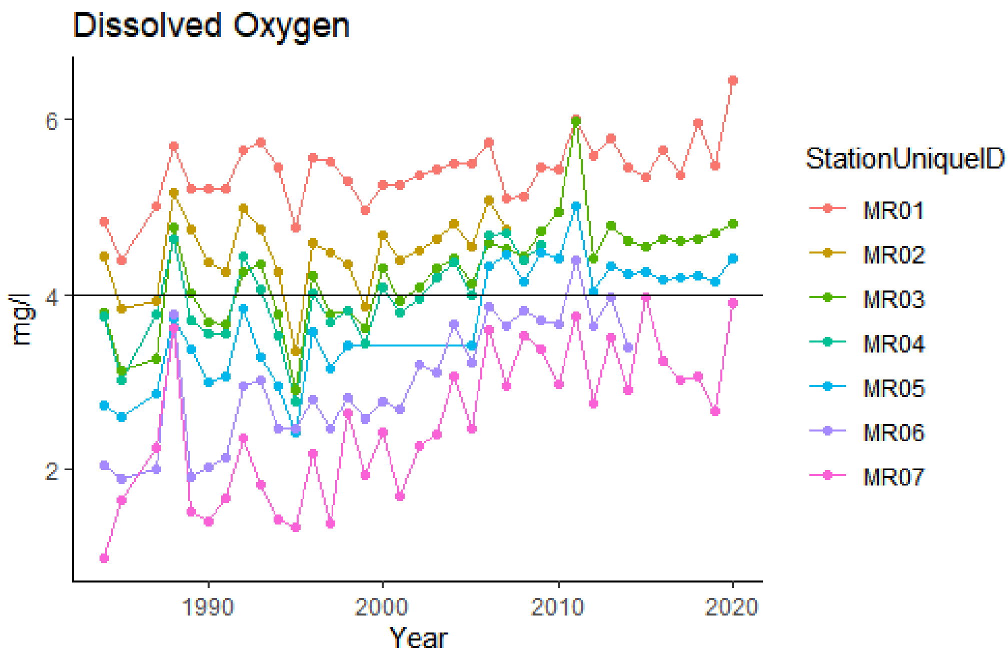

Figure 2.4: Dissolved oxygen at 7 sites across the Miami River from 1980 to 2020. Dissolved oxygen is highest at upstream sites and declines towards downstream sites. The black line at 4 mg/L represents county standards for dissolved oxygen.

Specific conductivity showed a spatial trend with the downstream most site (MR01) having the highest specific conductivity and consistently decreasing as the river transitions upstream towards freshwater system (Figure 2.5).

For other parameters, temperature had very low variability across sites (Appendix Figure A-6). Fecal coliform, although always exceeding the standard, was lowest in the most upstream site (MR07) and most downstream site (MR01; Appendix Figure A-7). Sites in between those two were highest in fecal coliform concentrations, exhibiting large spikes during the mid-1980s to mid-1990s, as also illustrated by the cumulative sums analysis. In the 1990s, in the mouth of the river (MR01) also had spikes in fecal coliform concentrations. Total coliform values (Appendix Figure A-8) were higher across all sites during the mid-1980s but were particularly high at MR02 and MR03. During the mid-1990s, these levels began to drastically decrease at all sites but MR06 and MR07 began to fall closer and slightly below the standard, except for a few spikes in the 2000s especially at sites MR02, MR03, MR04, and MR06. In the mid-2000s to 2010s levels of total coliform decreased at all sites.

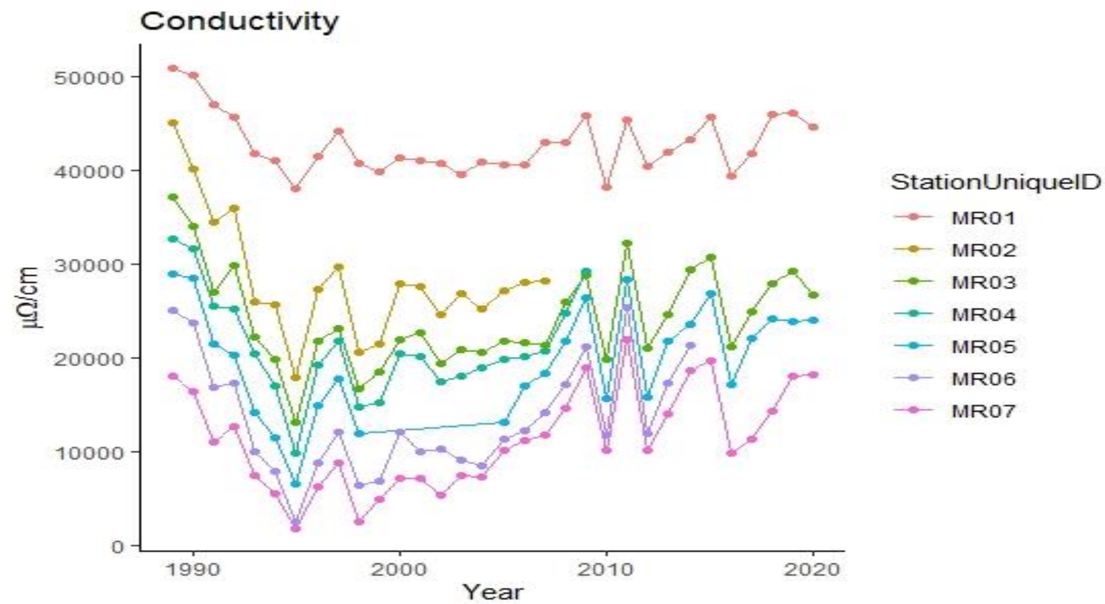

Figure 2.5: Specific conductivity at 7 sites across the Miami River from 1980 to 2020. Specific conductivity shows a spatial trend as the downstream sites have the highest conductivity levels, and as the river transitions upstream to a more freshwater system, conductivity decreases.

Temporal and spatial trends statistically supported by GLM analysis

The GLM analysis provided clarity on the strength and relative importance of temporal and spatial trends that were observed in the cumulative sums and scatterplot visualizations (Appendix Table A-1). For phosphorus, year was found to be influential, lending support for the prior analyses that showed a temporal trend in decreasing phosphorus. For nitrogen, site was found to be influential, but not year, suggesting that fluctuating levels of nitrogen concentrations over the last 40 years do not present a linear pattern of decreasing levels, even if the cumulative analysis suggests that nitrogen has at times been consistently below average. For dissolved oxygen, site and year were both influential. For specific conductivity, site was found to be influential, but not year. For temperature, neither year nor site were influential. For both fecal and total coliform, site but not year was influential.

Debris in the Miami River

Interviews with key informants about river debris presented a unique lens into an understudied element of water quality and river condition. In the Miami River, solid waste like mattresses and scooters to vegetation debris like palm fronds can be found (personal communication with boat captain and City of Miami employee) Single-use plastics, derelict vessels, animals sacrificed for religious purposes (e.g., chickens, ducks, birds, and goats), illicit substances, personal belongings, scooters, and mattresses are some of the debris that were observed along the Miami River. However, when participants were asked, “What is the most common debris they see in the river?” three interviewees mentioned single-use plastics, such as Styrofoam and plastic bags (Appendix Figures A-9 and A-10). These items cause navigation issues, as bags become entangled in boat propellers (personal communication with boat captain). During the wet season, there was more trash that makes its way to the river as the rain carries it (City of Miami employee). Hydraulic Vactor trucks remove all the trash from the pump stations and storm drains that gather debris before it goes into the river every two to four years. The range of trash in the Miami River is so broad that there is no categorical list recorded. Instead, trash removed by the Scavenger Boat in the Miami River is measured by weight. In cubic feet, daily averages from 2017 to 2020 were 30.48, 151.70 weekly, and 6830 yearly (Table 2-2). Yearly totals are represented in Table 2. 2021 was excluded as the data was obtained when the year was not yet complete. The trash collected by the Scavenger Boat is then shipped to a landfill. The Scavenger Boat 2000 has been contracted by the City of Miami since 2003 because of issues with debris in the river (City of Miami employee; Uchiyama, 2006). It travels longitudinally on the river once to twice a day, oxygenating the river as it collects debris in its receptacle. It has the ability to remove 260 cubic feet of trash and decontaminate 24 million gallons of water in one week through its decontamination mechanism: water enters the bow and ozone and oxygen are injected into the river (Uchiyama, 2006).

Table 2-2: *Averages of trash removed from the Miami River by the Scavenger Boat.*
*2021 excluded from this average

Year	**Yearly totals (cubic feet)**
2017	7460
2018	5760
2019	7320
2020	6780
2021 (January - August)	4689

Daily average (cubic feet)	**30.4847619**
Weekly average (cubic feet)	151.7014218
Yearly average* (cubic feet)	6830

The interviews revealed other issues in the river such as safety, navigation blocks, fuel leaks, human waste contamination, manatees being struck by boat propellers, storm drain runoff, and development along the Miami River. Key informants' opinions ranged from approval to concern on future plans regarding the river, yet all agreed that the condition and restoration efforts are improving the health of the river. One interviewee stated that the Miami River made them feel sad because it was a place with much potential, but it became very developed, and it reminds them of what could have been.

Other interviewees stated that the improving quality of the river could be seen as children and fauna like dolphins and fish were in the river and that they were proud of the efforts being made. Another interviewee stated that the river had undergone a lot of change as the river was not a safe place to be in the past nor was it healthy, and although to them it is still not healthy, it is a better place to be, and fish are coming back. They stated that they love the river despite all ongoing issues. Data from interviews contributed to identifying and quantifying debris in the river but also helped gain insight into human-river relations. The general theme present in respondents' comments appeared to be that although the Miami River contains trash and has pollution issues stemming from urbanization, it is improving in quality and is a meeting point for many types of people and a range of activities, despite its relatively small size and classification as a working river.

2.5 DISCUSSION

This study examined water quality along the urban gradient of the Miami River over several recent decades between 1978 and 2020, considering both physicochemical parameters and solid waste and debris in the river. A mixed method approach combined long-term trend quantitative analysis through the cumulative sums analysis, scatter plots, and GLM analysis in conjunction with qualitative analysis through stakeholder interviews.

The data shows that the quality of the Miami River generally improved over the past 40 years. This improvement in water quality in the early to mid-2000s was potentially related to new policies and restrictions about dumping and discharging in the river (Table 2-3), in addition to the rediscovery of the urban core (Rodriguez, 2020) and the emergence of watchdog organizations with restoration goals like the Miami River Commission in 2000 and later, Miami Waterkeeper. For instance, I found that phosphorus concentrations began to decrease beginning in early 2000s in comparison to values from the 1980s and 1990s. This suggests that policies or

Table 2-3: Policies Regarding the Miami River

Year	Policy	Action
1998	Miami River Commission • Dredging subcommittee • Economic development subcommittee • Stormwater subcommittee • Greenway subcommittee • Stormwater subcommittee • Urban infill subcommittee • Miami River Voluntary Improvement Plan	To act as the official coordinating clearinghouse for all public policy and projects related to the Miami River To develop coordinated plans, priorities, programs, projects, and budgets that might substantially improve the river area To act as the principal advocate and watchdog to ensure that river projects are funded and implemented in a proper and timely manner To unite all governmental agencies, businesses, and residents in the area on river issues -Miami River Commission
2000	Miami River Improvement Act	Provides findings and purpose; directs state and regional agencies to assist the Miami River Commission; requiring a plan; providing an appropriation; providing an effective date. "Directs state and regional agencies to work with the Miami River Commission, the City of Miami, and Miami-Dade County in considering an urban infill and redevelopment plan. Provides an appropriation." -Florida Senate
2001	Miami River Greenway Action Plan	"Aims for increased accessibility to residents and visitors. Marine industrial shipping activity will continue to thrive and prosper, land values will steadily improve, new recreational amenities will make the river a destination landscape, and an important element of Miami's natural and

		cultural heritage will be protected and enhanced for future generations to enjoy." -Miami River Commission
2020	City of Miami passed a Fertilizer Ordinance	Ordinance bans use of fertilizers during the rainy months May 15 through Oct. 31 and also bans the use of fertilizers near storm drains and bodies of water (50% slow releasing nitrogen and 0% phosphorus) -City of Miami

restrictions on nutrients and/or sewage discharge took place around the 2000s (Table 3). The GLM model of phosphorus indicated that year played a more important role than site, with values being more influenced by the temporal than spatial gradient of the data. There was also a spatial gradient for all parameters except temperature. An example of a clear spatial pattern is specific conductivity. The highest values for specific conductivity were recorded at MR01 and the lowest at MR07. This relates to MR01's proximity to the bay and a stronger salinity concentration compared to MR07, which was located farthest upstream away from the bay. However, as the river is brackish and it is a tidal river, rising sea levels could be impacting present-day salinity levels in the Miami River. Additionally, there are freshwater releases originating from Lake Okeechobee, Miami Canal, and the Miami River, all highly altered systems, that flow into the bay. Hurricanes could also have impacts on conductivity and salinity levels. A comprehensive study on salinity in the Miami River was conducted in 1966 (Leach and Grantham, 1966) but more up-to-date studies in the future could explore how salinity and thus conductivity have changed along the urban gradient of the Miami River through time. Dissolved oxygen and nitrogen concentrations seemed most influenced by site, in addition the fecal coliform and total coliform, suggesting that zones in the river could affect values for parameters. For instance, fecal and total coliform levels were highest at the middle river zones, which is the more residential zone, and lowest near the industrialized areas. This could be a reflection of wastewater leaks or discharges from houses and businesses in the upper river areas as well as households with dogs (Bojnansky, 2020). Projects are ongoing to convert around 1,000 properties on septic systems to sewage that will reduce a significant amount of wastewater from these systems between the Miami River and Little River area (Miami Dade County, 2021). There could be interactions between these geophysical gradients and human infrastructures occurring on this spatial scale that contribute, either in conjunction or separately, to the water quality of the river.

Spikes in phosphorus (with an EPA standard of 0.04 mg/L) in the Miami River possibly can be attributed to Miami's aging infrastructure, including leaky sewage pipes and septic tanks which can increase nutrient loads and coliform levels into the river and the bay (Bojnansky, 2020). If systems continue to age coupled with a growing city, there could be larger leaks than Miami has already been seeing. This issue is currently being managed and addressed by the City of Miami (MRC, n.d.; City of Miami, 2021). Leaky sewage pipes and agricultural activities like fertilizer application could be the reason why there are spikes in nutrients like phosphorous, nitrate, and nitrite after 2010 and in general, in addition to spikes in total coliform and fecal coliform (Bojnansky, 2020). If aging infrastructure is not eventually replaced, the river and the bay, would see spikes in these nutrients. A report for the Dade County Grand Jury from 1991 states that in the 1970's and 1980's, the Miami River had outfalls dumping raw sewage into it, explaining high nutrient and fecal and total coliform during these years. In 1987, six million gallons of raw sewage spilled into the river and Biscayne Bay as well as the river were completely closed to the public. This resulted from collapse of sewer lines under the river. Illegal sewage connections and old systems with no back-ups contributed to these collapses. In 2020 and 2021, fish kills in the bay continue to occur. Algal blooms in the bay have led to tens of thousands of fish and other marine life being killed due to nutrients entering the bay, combined with high temperatures and slow currents that led to lower oxygen levels (Tejedor, 2021). To mitigate this, there are ongoing projects of the City of Miami to replace septic systems with sewer systems and collect around 500,000 gallons of wastewater from failing or compromised septic systems by 2023 (Miami Dade County, 2021). Additionally, a fertilizer ordinance passed in 2021 that restricts usage of fertilizer 20 feet away from bodies of water and from disposing of fertilizer down storm drains, prohibiting usage of fertilizer with phosphorus while also limiting nitrogen application and requires slow releasing nitrogen mix, and prohibiting application of fertilizer during May 15 through October 31 (City of Miami, 2021; Miami Waterkeeper, 2021). Reduction of nutrients released into the Miami River that empty into the bay will reduce the amount of nutrients into the bay and may reduce the event of algal blooms leading to fish kills (Miami Herald Editorial Board, 2021).

Heavy rain transports pollutants which can contribute to poor water quality as the stormwater runoff drains into the river. Stormwater pollution can be exacerbated by flooding. Miami International Airport, Metro-Dade Transit Authority, and the City of Miami Sanitation Department also contributed to the declining health of the river during these years through fuel and oil pollution. Oil leaks originated from many sources like docks and cleaning vessels on the river, and difficult to pinpoint but are enforced by DERM through citations. Today, septic tanks, stormwater runoff, and sewage leaks are often considered the likely biggest factors impacting river health (Miami News Today, 2021). Another factor that could be impacting nutrient levels in the river could be discharges from Lake Okeechobee as that is the river's source and connected through the Miami Canal. There is high agricultural activity by the start of the Miami Canal from the Everglades Agricultural Area (EAA). Future research regarding the relation between the Miami River with the EAA and Miami Canal in conjunction with septic tanks could be beneficial to efforts in improving the quality of these waterways. Nutrient levels could be decreased through fertilizer bans as these would decrease the amount of nutrients washing into the river (Bojnansky, 2020). New regulations were put in place to eliminate the usage of fertilizers during the wet season to reduce runoff to canals and Biscayne Bay, in addition to restricting fertilizer usage 15 feet away from storm drains or canals and waterways (Miami Waterkeeper, 2020).

The health of the Miami River is important in maintaining human-river relations and its role as a modern, working urban river. For many, it can be a place to connect to nature in a crowded, bustling city. Yet, to have a functioning and healthy river, water quality must be kept at certain levels. If values of the analyzed parameters were to fall below thresholds, issues could ensue such as fish die-offs. This can occur in hot summer months such as July and August because of high temperatures (personal communication with City of Miami employee) that affect the amount of oxygen that can dissolve in water (Wetzel, 2003; Tejedor 2021). Foul smells and aesthetics could impact recreational activities and real estate projects. Industrial activity on the river can also have impacts on the river's health. Longitudinal connectivity can play a crucial role in its health since the river is connected to Lake Okeechobee through the Miami Canal which connects to the Miami River and empties into Biscayne Bay. Therefore, the river influences the health of the bay. Restoration projects could disrupt modern usage of the river. However, starting in the 1990s and 2000s, we see that laws and watchdog organizations put in place helped the river achieve healthy levels while the river continued to grow into an important cultural and economic hub. As the river became an important asset of the city and its people, this was reflected in the river's changing morphology.

The severe change the river underwent beginning from the construction of the Miami Canal in 1909 to present times resulted in the Miami River to display symptoms of USS. As the river's quality diminished, calls for the clean-up of the river began (Gaby, 1993) and there was a shift in the perception of the Miami River beginning near the late 1990s. The debris, sewage discharges, and nutrient inputs could be reduced in the river while maintaining its industrial and commercial functions. Although the Miami River's morphology could not be returned to its original state complete with its rapids and spring sources, USS symptoms could be addressed. This restoration can be seen through nutrient levels. Before the 2000s, nutrient levels were higher and oxygen was lower, reflecting growing urbanization without much regard to the river. After the 2000s, the river underwent a period of rediscovery and restoration, likely as a result of more regulations (Table 2-3). As the Miami River's quality continues to improve and conditions are improving like increasing oxygen levels and decreased nutrient levels, we can see the Miami River as part of a novel ecosystem running through the middle of the City of Miami, incorporating concepts from ecology for the city as we learn to embrace the river's title as a working river.

Additional steps are being taken to ensure that the health of the river is maintained. The Scavenger Boat 2000 (Appendix Figure A-11) travels up and down the river to oxygenate the water as well as collect debris. In the 2000s, I observed increasing dissolved oxygen values in the DERM data, which could be directly correlated to the oxygenation of the river through the Scavenger Boat. The boat works once to twice a day, Monday to Fridays except for major holidays, helping mitigate effects of USS in the Miami River. Derelict vessels, which were mentioned by interviewees, are also being removed by the county, as these can cause gasoline leaks in the river. There are also laws in place that protect the river from pollutants; laws such as not allowing boats to be washed on the river itself and is enforced through fines (personal communication with City of Miami employee). The Miami River Commission also serves as a watchdog organization where people from the community, including business owners, residents, and government employees, come together to discuss concerns, issues, or ideas about the river. Issues discussed by the Miami River Commission range from derelict vessels, new businesses, the Riverwalk, transportation, new residences, the Scavenger 2000, shoreline cleanups, and zoning issues. The stormwater subcommittee and greenway subcommittees also discuss further topics, such as imposing restrictions on infrastructure, construction of new buildings in different zones (based on zoning laws), and permits are ways in which the river is being protected.

Additionally, the limitation by the city of single use plastics, like plastic grocery bags, is something that can be done to decrease plastic debris in the Miami River and improve its health. There are current plans to add more filters in stormwater drains to catch plastics before they make their way into the river an initiative called the Stop Ocean Pollution Program (personal communication, City of Miami employee). Raising awareness and educating the public can be a way that debris is reduced, and water quality is improved. Knowing the amount, type, and origin of the trash allows for better management as well as reduction of debris (Emmerik and Schwarz, 2019) would not only help the Miami River but also Biscayne Bay (Bojnansky, 2020). Miami Riverday Festival helps raise awareness about the Miami River and celebrates the mixed-use working river, with environmental education, historic tours, and river rides in addition to activities for families and children, as well as musical performances (Miami River Commission Flyer, 2018). Research like the Circularity Assessment Program that looks into the origins of debris, how trash is disposed, how to integrate citizen science through trash-tracking apps allows for collaboration between researchers and local policymakers (Ocean Conservancy, 2021). It is imperative to include the community as well through educational events like festivals mentioned above or anti-litter campaigns in addition to the implementation of infrastructure (Bauer-Civello et al., 2019) such as those from the Stop Ocean Pollution Project. There has been a growth in riverine debris research but is still understudied in comparison to marine debris but no less important (Emmerik and Schwarz, 2019).

Urban rivers, like the Miami River, have a unique place in modern, urban society as they provide an aquatic habitat in a setting where functioning, healthy ecosystems are scarce or non-existent (Walsh et al., 2005). The Miami River is a working river that brings different types of people and businesses together. Both ecological and social aspects are important when considering restoration, management, and access to rivers. Urban rivers continue to be an understudied field and require further research to be able to fully grasp interactions between landscape dimensions, ecological processes, and social processes as well.

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APPENDIX

Figures

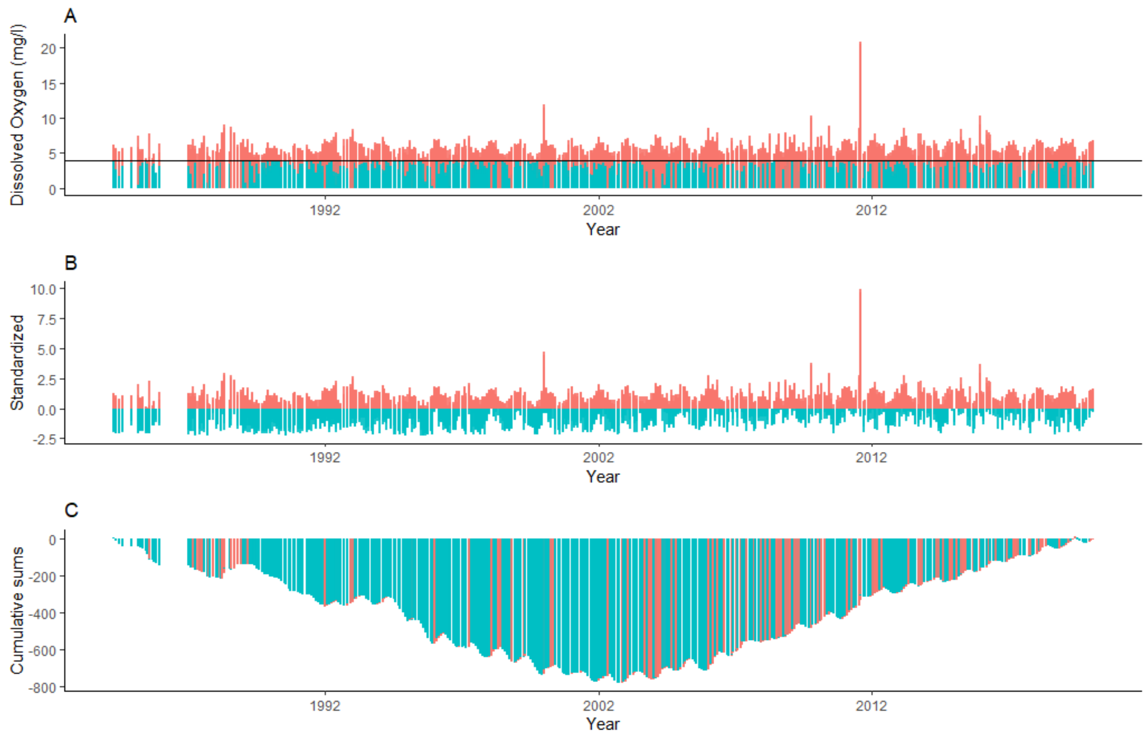

Figure A- 1: For dissolved oxygen, Box A depicts the values of dissolved oxygen in the Miami River across all sites and the black line is the county standard at 4 mg/L. Box B shows standardized values, where dissolved oxygen values across all sites where subtracted by the average of the data set for dissolved oxygen and divided by the standard deviation while Box C shows cumulative sums of the standardized values, showing shifts in the data as it moves below or above average. Values above average are depicted in red and below average values are depicted in blue.

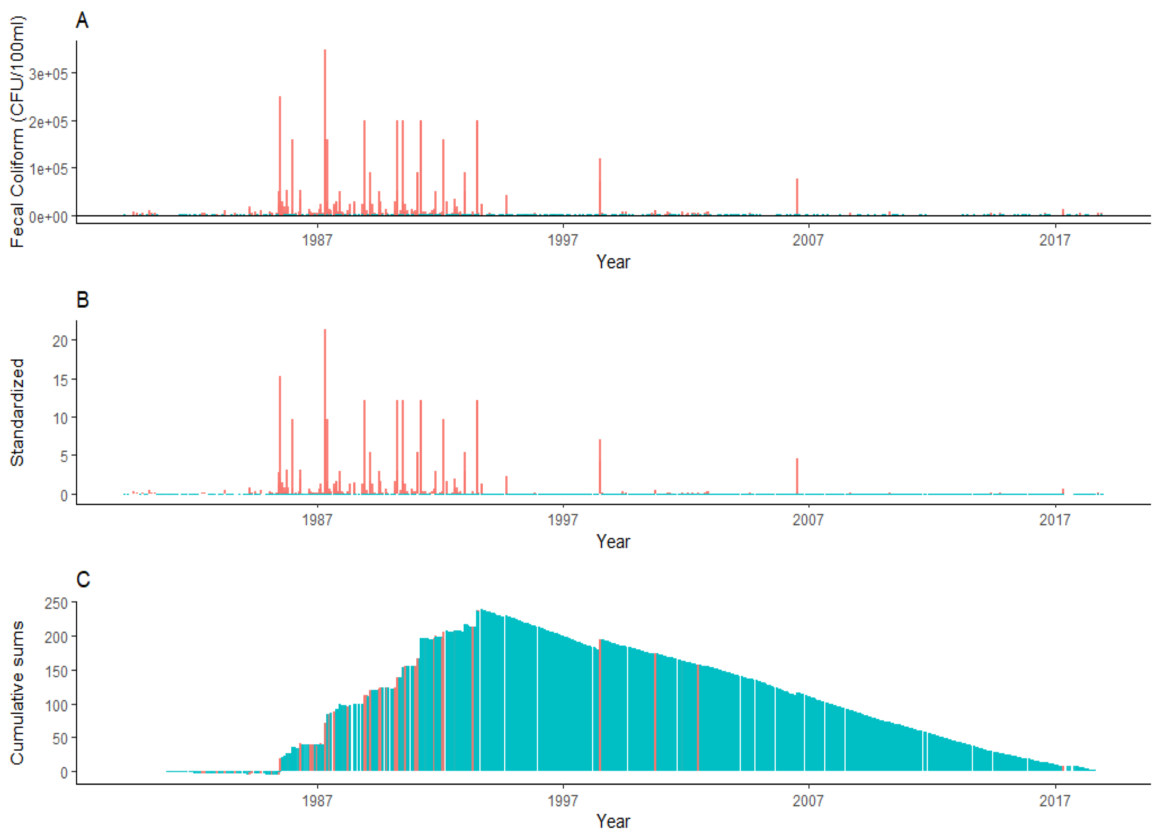

Figure A- 2: For fecal coliform, Box A depicts the values of fecal coliform in the Miami River across all sites and the black line is the county standard at 0 CFU/100 ml. Box B shows standardized values, where fecal coliform values across all sites where subtracted by the average of the data set for fecal coliform and divided by the standard deviation, while Box C shows cumulative sums of the standardized values, showing shifts in the data as it moves below or above average. Values above average are depicted in red and below average values are depicted in blue.

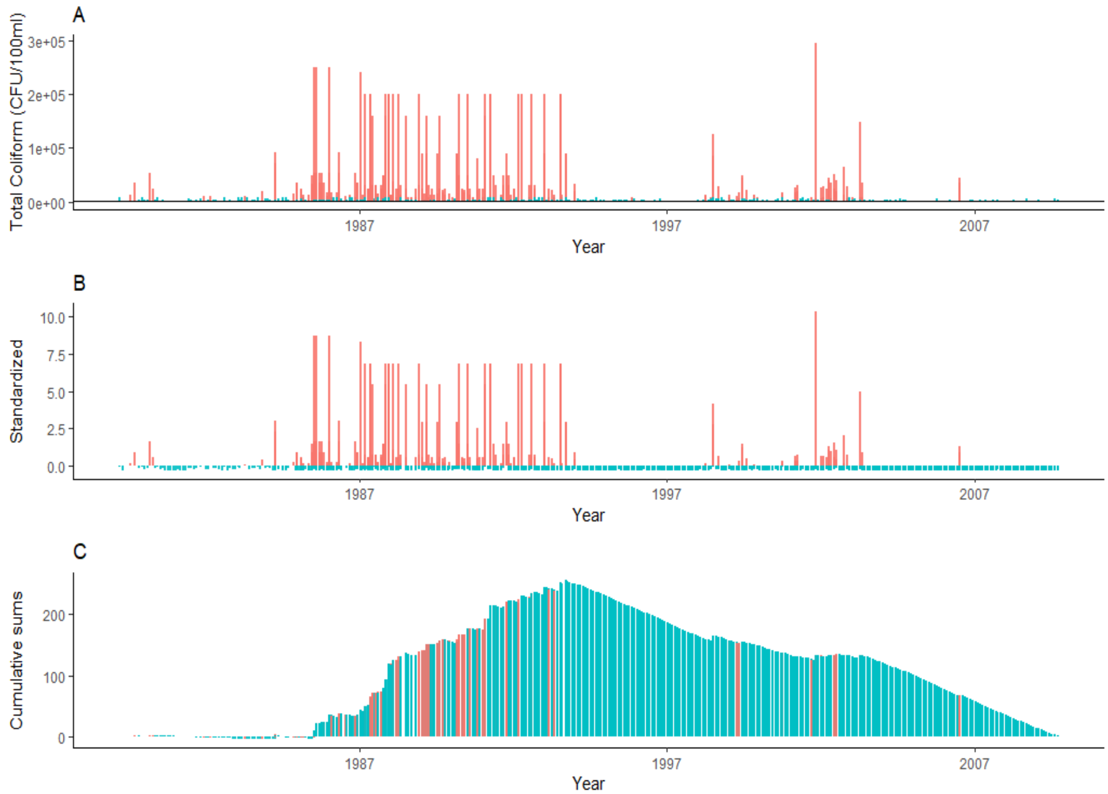

Figure A- 3: For total coliform, Box A depicts the values of total coliform in the Miami River across all sites and the black line is the county standard at 0 CFU/100 ml. Box B shows standardized values, where total coliform values across all sites where subtracted by the average of the data set for total coliform and divided by the standard deviation while Box C shows cumulative sums of the standardized values, showing shifts in the data as it moves below or above average. Values above average are depicted in red and below average values are depicted in blue.

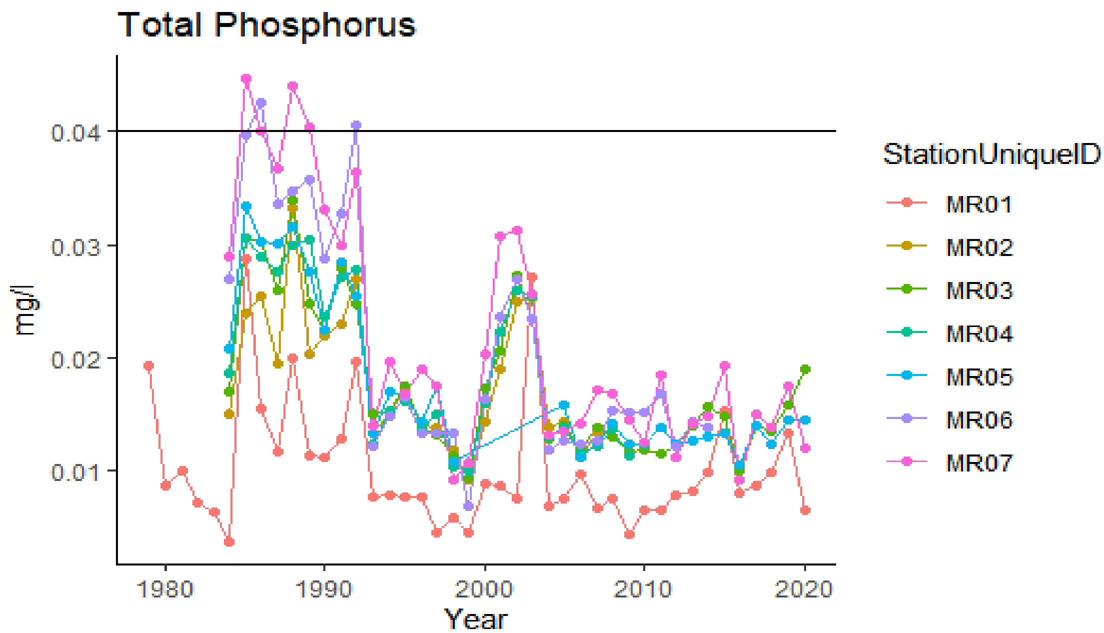

Figure A- 4: Total phosphorus at 7 sites across the Miami River from 1980 to 2020. Total phosphorus values by site, differentiated by different colors, in the Miami River. The black line at 0.04 mg/L represents the EPA standard for total phosphorus.

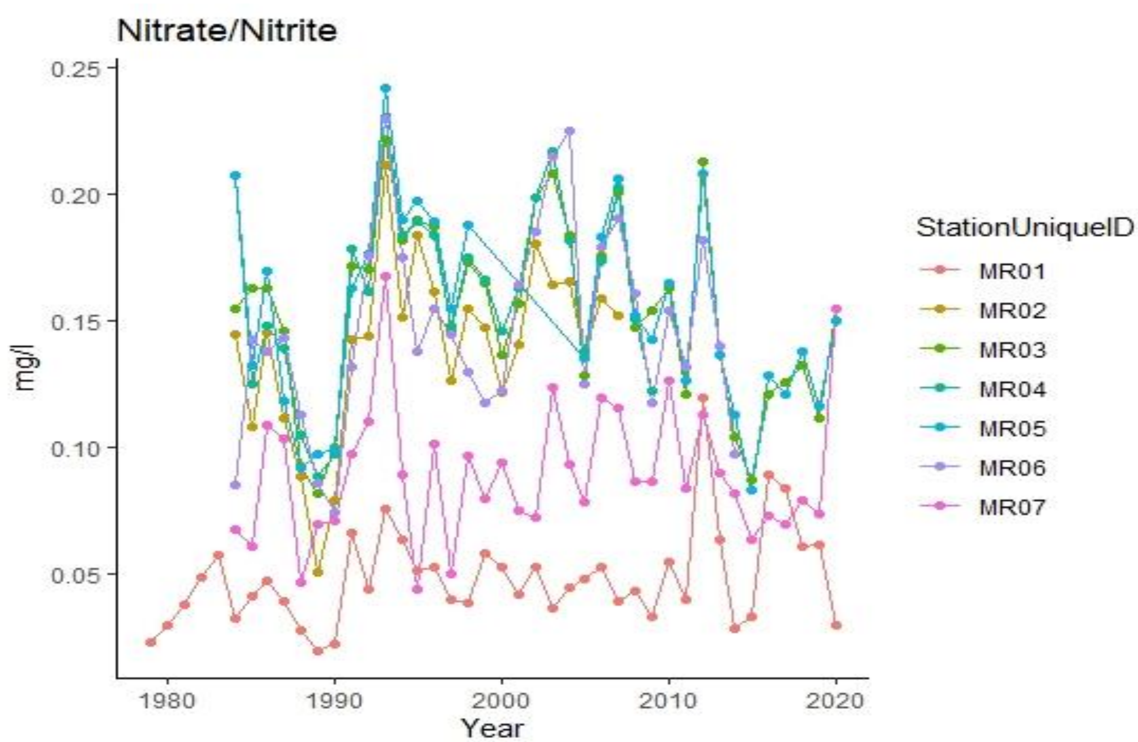

Figure A- 5: Nitrate and nitrite at 7 sites across the Miami River from 1980 to 2020. Nitrate and nitrite values by site, differentiated by different colors, in the Miami River.

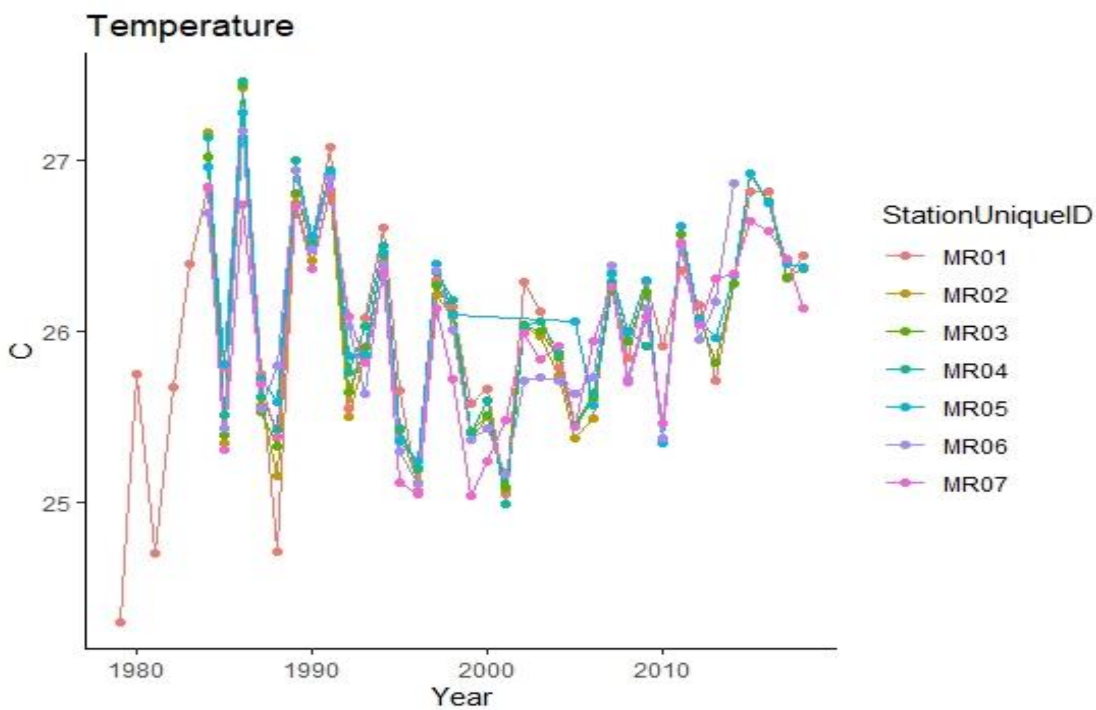

Figure A- 6: Temperature at 7 sites across the Miami River from 1980 to 2020. Temperature values by site, differentiated by different colors, in the Miami River.

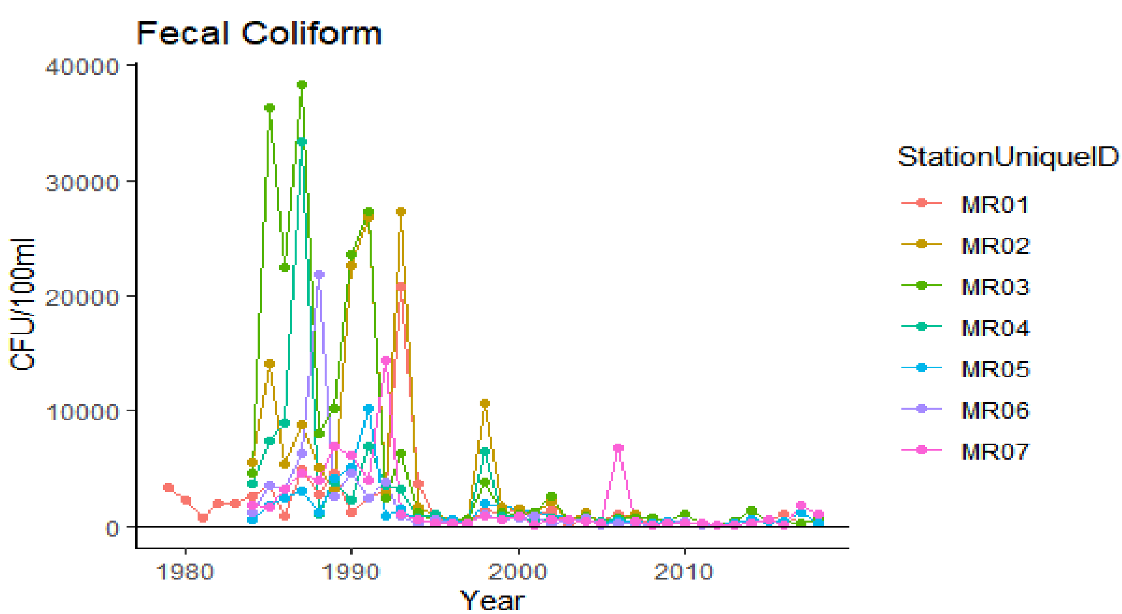

Figure A- 7: Fecal coliform at 7 sites across the Miami River from 1980 to 2020. Fecal coliform values by site, differentiated by different colors, in the Miami River. The black line at 0 represents the Florida Department of Environmental Protection standards.

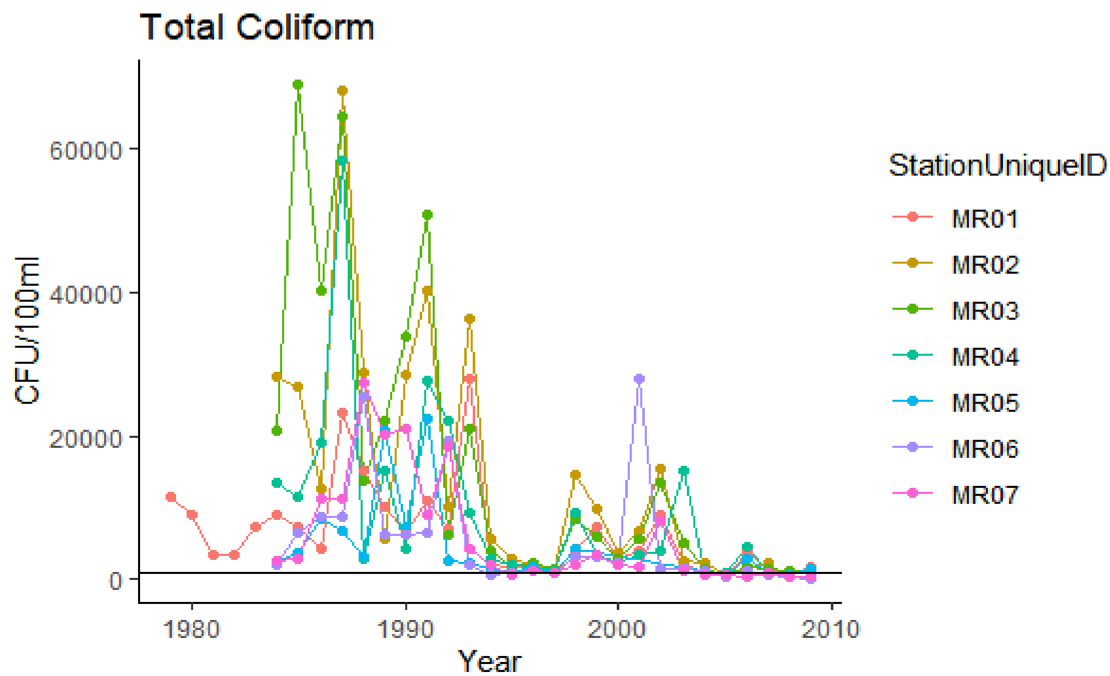

Figure A- 8: Total coliform at 7 sites across the Miami River from 1980 to 2010. Total coliform values by site, differentiated by different colors, in the Miami River. The black line at 1000 CFU/ 100 mL represents the county's standard for total coliform.

Figure A- 9: Single use plastics such as bottle caps, wrappers, and Styrofoam near Riverside.

Figure A- 10: Plastic bag on the Miami River near Jose Marti Park.

Figure A- 11: Scavenger Boat 2000, collecting debris. Scavengevessel.com

Table A- 1: Generalized Linear Model (GLM) Table

Generalized linear mixed model for water quality parameters with increasing AIC scores (i.e., lowest AIC scores at the top). Year represents the temporal dimension whereas site represents the spatial dimension. Lowest IAC scores have the most impact on parameter value. For instance, in the case of phosphorus, year is more important than site in telling us about what impacts the values.

Response Variable	Model	AIC	ΔAIC
P	Year	-14370.8	0.0
	Site	-14309.0	61.8
	Null	-14158.7	212.1
NOx	Site	-5765.5	0.0
	Year	-5106.6	658.9
	Null	-5106.1	659.4
DO	Site	25808.6	0.0
	Year	27945.8	2137.2
	Null	28268.1	2459.5
SPC	Site	144858.2	0.0
	Year	147192.5	2334.3
	Null	147192.6	2334.4
Temp	Null	36063.8	0.0
	Year	36064.6	0.8
	Site	36068.9	5.1
Fecal Coli	Site	56519.7	0.0
	Null	56535.7	16.0
	Year	56538.5	18.8
Total Coli	Site	47988.1	0.0
	Null	48015.4	27.3
	Year	48018.4	30.3

Guiding Questions for Interviews

1. What change has there been, or have you seen, on the river since you have lived on or worked on the river?

2. How has the demographic, infrastructure, or scene changed?

3. What is the most surprising thing you have seen on the river?

4. What makes the Miami River unique?

5. Have you observed any fish or wildlife in the river?

6. What other work has been conducted in the river and what type of data is available to the public?

7. How has debris in the river changed over time?

8. What is the most common trash seen nowadays? What was most surprising trash found or seen?

9. Where does the trash come from and is it more concentrated in certain areas?

10. How often is river debris collected, how much is collected, and what is done with it afterwards?