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Historical Loss and Current Rehabilitation of Shoreline Habitat along an Urban-Industrial River—Detroit River, Michigan, USA

John H. Hartig [1,*] and David Bennion [2]

1 U.S. Fish and Wildlife Service, Detroit River International Wildlife Refuge, 9311 Groh Road, Grosse IIe, MI 48138, USA

2 U.S. Geological Survey, Great Lakes Science Center, 1451 Green Road, Ann Arbor, MI 48105, USA; dbennion@usgs.gov

* Correspondence: john_hartig@fws.gov; Tel.: +1-734-692-7608

Academic Editor: Tan Yigitcanlar

Received: 27 February 2017; Accepted: 9 May 2017; Published: 15 May 2017

Abstract: The purpose of this study was to evaluate the historical loss and current shoreline habitat rehabilitation efforts along the urban-industrial Detroit River using geographical information system methods and a shoreline survey. This study found a 97% loss of historical coastal wetlands to human development. By 1985, 55% of the U.S. mainland shoreline had been hardened with steel sheet piling or concrete breakwater that provide limited habitat. Since 1995, 19 projects were implemented, improving 4.93 km of shoreline habitat. A comparison of the 1985 and 2015 georeferenced aerial imagery showed that 2.32 km of soft shoreline was also converted to hard shoreline during this timeframe. Of the 19 projects surveyed, 11 representing 3.35 km made habitat improvements to shoreline that was already georeferenced as "soft", three representing 360 m converted shoreline from "hard" to "soft", and five representing 1.22 km added incidental habitat to hardened shoreline. Even with the addition of 1.58 km of new soft shoreline and incidental habitat, there was an overall net loss of 0.74 km of soft shoreline over the 30-year timeframe. To reach the "good" state of at least 70% soft shoreline, an additional 12.1 km of soft shoreline will have to be added. This confirms that shoreline hardening continues despite the best efforts of resource managers and conservation organizations. Resource managers must become opportunistic and get involved up front in urban waterfront redevelopment projects to advocate for habitat. Incremental progress will undoubtedly be slow following adaptive management.

Keywords: soft shoreline engineering; urban-industrial river; habitat restoration targets

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1. Introduction

The Laurentian Great Lakes are a globally significant aquatic resource, containing approximately 22,900 cubic km (5500 cubic miles) of water that represent nearly one-fifth of the standing freshwater on the Earth's surface. The Great Lakes drainage basin covers more land than England, Scotland, and Wales combined, and the lakes together have over 17,000 km (10,000 miles) of shoreline. This system is an inter-connected chain of lakes where waters from the Upper Great Lakes (i.e., Lakes Superior, Michigan, and Huron) flow to the Lower Great Lakes (i.e., Lakes Erie and Ontario) through a series of connecting channels. These waters eventually flow through the Gulf of St. Lawrence to the Atlantic Ocean.

Situated at the heart of the Laurentian Great Lakes is the Detroit River. It is a 45.3-km Great Lakes connecting channel through which the entire Upper Great Lakes flow to the Lower Great Lakes. The Detroit River provides 80% of the water inflow to Lake Erie [1]. Detroit River is not only unique for the consistent volume of water that flows through it (average flow rate: 5200 m^3 s^{-1}), but for its diversity of fish and wildlife, and critical habitats (Table 1).

Table 1. Examples of exceptional natural resource attributes of the Detroit River [2].

Natural Resource Attribute	Description
Birds	• Over 350 species of birds have been identified in the river corridor • Detroit River is situated at the intersection of the Atlantic and Mississippi Flyways • 30 species of waterfowl have been documented using the Detroit River; more than 300,000 diving ducks use the lower Detroit River as stopover habitat during spring migration • The lower Detroit River is one of the three best places to watch raptor migrations in the U.S.; 23 species of raptors migrate through the lower Detroit River; birders have seen over 100,000 raptors migrating in a single fall day • The lower Detroit River has been identified as an "Important Bird Area" (i.e., sites that provide essential habitat for one or more species of birds) by the National Audubon Society • In 2011, Ducks Unlimited identified Detroit as one of the top ten metropolitan areas for waterfowl hunting in the U.S. • Detroit River and western Lake Erie offer exceptional birding opportunities; a ByWays to FlyWays Bird Driving Tour Map features 27 unique birding sites in southwest Ontario and southeast Michigan
Fish	• 113 species of fish have been identified in the Detroit River • Detroit River wetlands provide spawning areas for 26% of the fish species in the Great Lakes • An estimated 10 million walleye ascend the Detroit River from Lake Erie each spring to spawn, creating an internationally renowned sport fishery • Detroit River and Lake Erie are considered the "Walleye Capital of the World"; major international fishing tournaments, sponsored by FLW Outdoors and other organizations, are held annually on the Detroit River and western Lake Erie offering prize money of as much as $1.5 million
Biodiversity and International Designations	• The Detroit River and western Lake Erie have been recognized for their biodiversity in: the North American Waterfowl Management Plan (one of 34 waterfowl habitat areas of major concern in the U.S. and Canada); the United Nations Convention on Biological Diversity (i.e., Detroit River and western Lake have identified as areas to receive biodiversity protection and conservation); the Western Hemispheric Shorebird Reserve Network (i.e., marshes along the lower Detroit River and northeast Ohio have been identified a Regional Shorebird Reserve); and the Biodiversity Investment Area Program of Environment Canada and U.S. Environmental Protection Agency (i.e., the Detroit River-Lake St. Clair ecosystem has been identified as one of 20 Biodiversity Investment Areas in the Great Lakes) • Humbug Marsh in Trenton and Gibraltar, Michigan, USA has been designated as a "Wetland of International Importance" (i.e., wetlands protected by national governments to fulfill obligations under the international Ramsar Convention) • The Detroit River is part of the Detroit River International Wildlife Refuge, the only international wildlife refuge in North America • The Detroit River is the first river in North America to receive both American Heritage River and Canadian Heritage River designations

On the U.S. side of the Detroit River is the City of Detroit, Michigan, USA, a city founded in 1701 that is older than the U.S. and considered the automobile capital of the nation. On the Canadian side of the Detroit River is the City of Windsor, Ontario, Canada that was settled in 1748 and today is considered the automobile capital of Canada. The watersheds of the U.S. and Canadian sides of the Detroit River have populations of over 4,000,000 and nearly 390,000, respectively.

The Detroit River has a long history of industrial development dating back to ship-building and maritime operations. Indeed, it was common practice in the 20th century to utilize hard shoreline engineering as part of commercial shoreline development. Hard shoreline engineering is generally defined as the use of concrete breakwaters or steel sheet piling to:

- stabilize shorelines for protection from flooding and erosion;
- achieve greater human safety; and
- accommodate commercial navigation or industry [3].

Although hard shoreline engineering can achieve commercial, navigational, and industrial benefits, it typically results in negative ecological impacts because it provides limited habitat and often restricts access to adjacent habitats. For example, sea walls and bulkheads provide less physically complex habitats, as compared with natural shorelines, and generally support fewer species of benthic fauna, mobile crustaceans and fish [4–8]. Such anthropogenic hardening of shorelines not only destroys natural features and biological communities, but it also alters the transport of sediment, disrupting the balance of accretion and erosion of materials carried along the shoreline by wave action and long-shore currents [9]. This disruption of sediment transport processes can intensify the effects of erosion, causing ecological and economic impacts [10].

This management paper will review and evaluate the historical loss and degradation of shoreline habitats on the U.S. side of the Detroit River, current state of efforts to rehabilitate shoreline habitat based on a comprehensive survey, and the trends of shoreline rehabilitation against quantitative targets to strengthen the science-policy linkage and better support ecosystem-based management.

2. Materials and Methods

2.1. Geographical Information System (GIS) Methods

Georeferenced aerial imagery acquired in 1985 and 2015 was used to map hardened versus soft shoreline lengths for each year. Hardened shoreline was defined as concrete wall, steel sheet pile, or other material that formed a vertical interface with the waterline. Anything else was labeled soft shoreline, including concrete rip-rap. Due to the lower resolution of the 1985 imagery, concrete rip-rap shoreline appears as mottled dark and light colors, and is more sinuous than the consistently colored, linear vertical walls used for shore protection. Due to these issues, rip-rap could not reliably be differentiated from other soft shoreline types which necessitated its inclusion in that category. Both sets of images were digitized on screen using ArcGIS 10.4.1 and were examined at a 1:3000 scale. Imagery from 1981 was used to fill in coverage gaps in the 1985 image set. This process resulted in a shapefile representing the extent of hard and soft shoreline for each year. Total lengths of each attribute type were then calculated.

Wetland loss was calculated by comparing digitized wetland extents from a map created in 1796 (Figure 1) and General Land Office (GLO) surveys from circa 1800 to current National Wetland Inventory maps [11,12]. While each of these historic sources has known accuracy issues, they represent the only pre-industrial data available. This limitation is illustrated by the fact the areal extents of mapped wetlands do not completely coincide. However, total area indicated by each source was in close agreement.

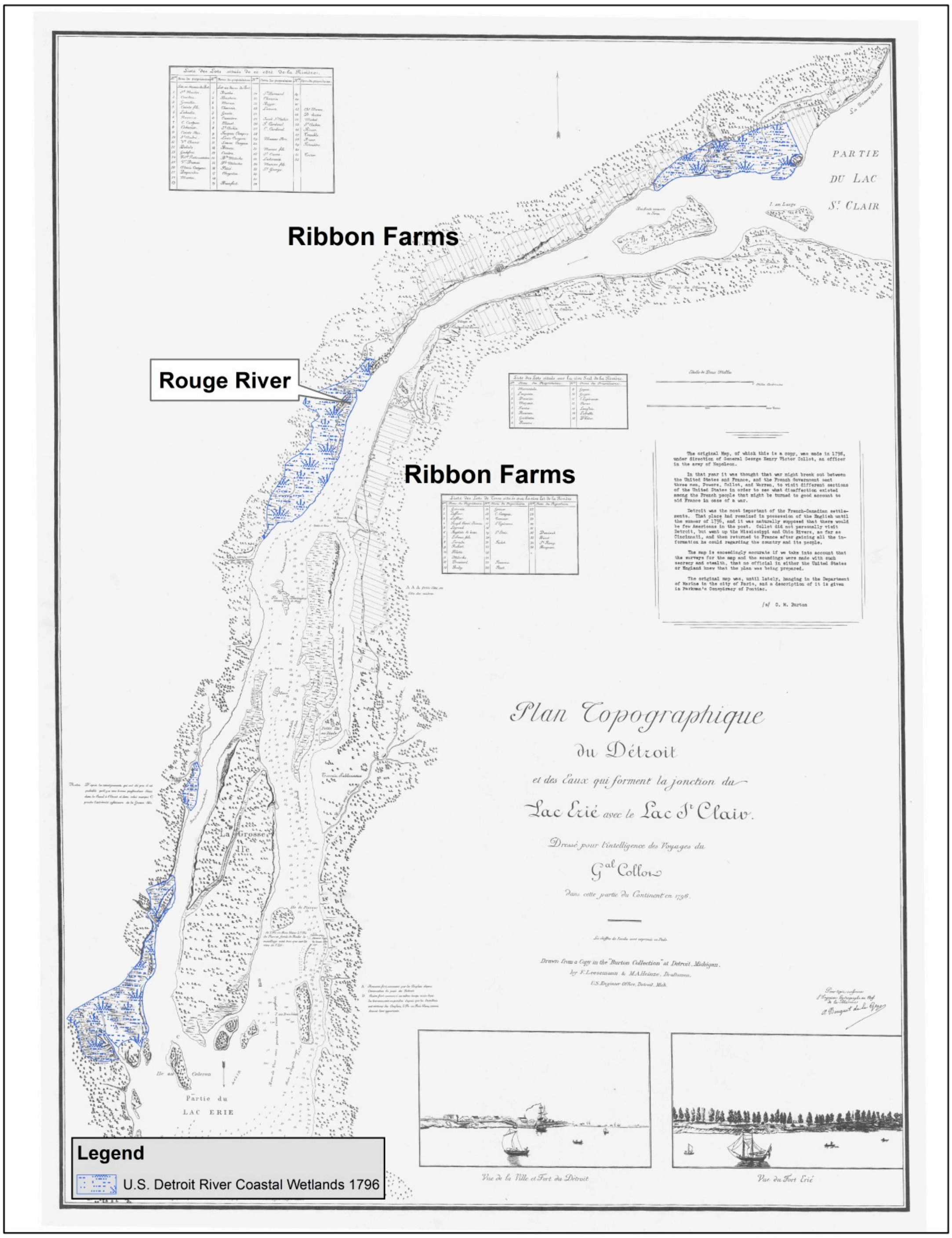

Figure 1. Historical map of the Detroit River shoreline showing wetlands and early ribbon farms, 1796 (map credit: National Oceanic and Atmospheric Administration's Office of Coast Survey).

2.2. Soft Shoreline Survey Methods

In 2015–2016, a survey of soft shoreline engineering projects along the U.S. mainland shoreline of the Detroit River was performed to document project goals, nature of work, costs, timeframe, partners, and post-project monitoring of effectiveness. For the purposes of this survey, soft shoreline engineering was defined as any project that added some aquatic and riparian shoreline habitat, including:

- soft shoreline engineering—the use of ecological principles and practices to reduce erosion and achieve stabilization and safety of shorelines, while enhancing riparian habitat, improving aesthetics, and even saving money [3,13];
- incidental habitat (i.e., adding habitat components to a structure like a breakwater), or
- changing from steel sheet piling or concrete breakwater to some limestone rip-rap that provided some limited habitat features.

From a habitat perspective, all three of the categories above are superior to steel sheet piling or concrete breakwater, however, soft shoreline engineering is more beneficial than incidental habitat and rip-rap. It is recognized that negative physicochemical and biological impacts of rip-rap have been documented [9,14], including decreasing habitat complexity and reducing connectivity to terrestrial habitats [15,16]. In Lake St. Clair, rip-rap hardening altered shoreline morphology and invertebrate communities, and impaired terrestrial-aquatic resource exchanges [17]. However, other studies have shown that rip-rap does provide fish habitat with interstitial spaces for cover and food production, and habitats for other organisms [18,19]. Indeed, lake whitefish have been found to spawn on rip-rap in the Detroit River off Fighting Island [20]. Lake sturgeon have been found to spawn off rip-rap in Lake Winnebago in Wisconsin [21]. Therefore, for the purposes of this survey changing from steel sheet piling or concrete breakwater to rip-rap in a consistently high flow river is considered a form of soft shoreline because it provides some habitat features.

Comparable data have not been compiled on Canadian side of the Detroit River and therefore could not be incorporated in this study.

3. Historical Background

As an illustration of anthropogenic impacts on the U.S. portion of the Detroit River shoreline, it is worth reviewing a brief history of Detroit. Native Americans lived along the Detroit River for over a millennium before Europeans came to the region. In 1701, Antoine de la Mothe Cadillac founded Detroit as a French trading post and garrison to expand trade and commerce [22]. To help establish Detroit as a full-service community that was self-supporting, Cadillac began awarding ribbon farms soon after he arrived in 1701. These ribbon farms were long, narrow, land divisions lined up perpendicular to the Detroit River. Figure 1 shows how ribbon farms had been established along much of Detroit's riverfront by 1796. Such agricultural practices were undoubtedly some of the first European impacts on the Detroit River shoreline and its coastal wetlands, especially filling wetlands.

As Detroit grew into a center of commerce and trade, a number of wharfs were constructed starting in 1760 that projected into the Detroit River. This encroachment of wharfs and docks into the Detroit River continued for many years through the latter 18th century. Such encroachment into the river also led to loss of coastal wetland habitats [23].

In 1805, a devastating fire occurred that destroyed all wooden structures in a single day. Soon after this "Great Fire of 1805" the city was re-platted, projecting lots into the Detroit River. These new platted lots, including a portion of the Detroit River, were now part of the city. Debris from the fire was used to help fill in the coastal wetlands of the Detroit River.

The physical configuration of Detroit's waterfront continued to change. In 1816, a wharf 3 m wide and extending 61 m into the Detroit River was authorized [24]. In 1818, Walk-In-The-Water, the first steamboat on the upper Great Lakes, arrived in Detroit, which encouraged new settlers—the normal two-week voyage across Lake Erie was cut down to just a few days. Regular cruise schedules were soon established between Buffalo, New York, and Detroit.

Such improved water transportation expanded Detroit's population. Detroit's population increased from 900 in 1817 to 2200 in 1830 to 9700 in 1837. Indeed, the Detroit River became so busy with steamboats and sailing vessels that it was declared a "public highway" by U.S. Congress in 1819 [24], furthering the development of the shoreline for commerce and degrading habitats.

In 1827 the Detroit City Council voted to further improve its waterfront facilities with a 18.3-m wide dock at the foot of Woodward Avenue. By September of 1827, this embankment project (as it was called at that time) was completed that provided a convenient safe landing for vessels and improved the "filthiness" associated with the wharfs that was perceived to be causing waterborne diseases [25]. During this project and at the same time that they were demolishing Fort Shelby in Detroit, abandoned earth works from the fort were used to fill in the riverfront, in addition to debris from the "Great Fire of 1805". In total, this embankment project resulted in human encroachment of an estimated 0.5 km into the river. A combination of timber framing and earth was used to create a new wharf at the expense of the river's wetland and riparian habitats.

It would not be until the 1890s that the U.S. Army Corps of Engineers would initially establish harbor lines in the Detroit River to regulate where piers and other structures could be built. During this time shoreline filling activities were allowed landward of harbor lines without federal approval or authorization. This policy became official in 1899 with the signing of the Rivers and Harbors Act. Section 10 of this Act prohibited the creation of any obstruction not authorized by Congress to the navigable capacity of any waters of the United States. Further, it stated that it was unlawful to "build or commence the building of any wharf, pier, dolphin, boom, weir, breakwater, bulkhead, jetty, or other structures in any port, roadstead, haven, harbor, canal, navigable river, or other water of the United States, outside established harbor lines". During the late-1800s, 8 km of Detroit River waterfront were almost continuously lined with docks [24].

It should also be noted that three creeks (i.e., 2-km Savoyard Creek, 4-km May's Creek, and 5.6-km Bloody Run) in Detroit that emptied into the Detroit River were either filled in or covered over to make way for streets and building sites in Detroit [23,26]. Not only were these streams lost through development, but their floodplains and wetlands were destroyed, eliminating the ecosystem services or life-sustaining benefits they provided to Detroit.

Detroit's population grew from approximately 45,000 in 1860 to over 285,000 in 1900 [27]. Much of this growth was attributed to the development and growth of manufacturing. For example, in direct response to Detroit's strategic location in the heart of the Great Lakes, the demand for transportation of passengers and goods, and the availability of essential resources, Detroit became one of the greatest ship-building ports in the United States [28].

Henry Ford built his first car in Detroit 1896, followed by Ransom E. Olds opening Detroit's first automobile manufacturing plant in 1899. Henry Ford then introduced the assembly line in 1913. In 1904, 3.8% of Detroit's 60,554 industrial employees were employed in the automobile industry [29]. By 1919, 45% of Detroit's 308,520 industrial employees were employed in the automobile industry [29]. Detroit was now the "Motor City" and one of the largest industrial manufacturing centers in the world.

By the middle of the 20th century one in six American jobs was connected to the automobile industry and Detroit was its epicenter [30]. It should be no surprise that Detroit reached the apex of its population growth in 1950 with 1.85 million people. During this time the shoreline of the Detroit River was incrementally altered/modified to meet the needs of commerce and industry.

4. Results and Discussion

Based on detailed analyses of the 1796 historical map, GLO survey data, current National Wetlands Inventory data, and recent georeferenced imagery, the U.S. shoreline of the Detroit River has lost approximately 97% of its coastal wetlands to human development (Figure 2). Analysis of the 1796 map produced a total of 1968 ha of coastal wetlands, and the GLO source indicated 2048 ha. Current National Wetlands Inventory data show only 56 ha of connected wetlands remain. In addition, by 1985 55% of the U.S. mainland shoreline had been hardened with steel sheet piling or concrete breakwater, leaving only 45% in a soft shoreline state that provided aquatic and riparian habitat.

Since the 1950s, Detroit experienced considerable loss of population (over a 60% decline since 1950) and industry, rising unemployment, increased cost of living, decreased access to city services, and increased crime. This industrial decline, population emigration, loss of jobs, and concomitant other socio-economic problems culminated in 2013 when Detroit became the largest city in the United States to ever go through bankruptcy. There were now fewer people and industries, and much underutilized and undervalued riverfront land. Citizens had literally lost their connection to the Detroit River.

With the decrease in the Detroit Metropolitan Area's industrial activity (particularly on the waterfront), the expansion of other modes of transportation (i.e., more goods and people being transported by rail, highway, and air), a growing environmental consciousness (i.e., more people being aware of how they are part of an ecosystem and what they do to their ecosystem they do to themselves), and the growing public interest in close-to-home, outdoor recreation, there has been a unique opportunity and growing interest in reclaiming and redeveloping portions of the waterfront for multiple purposes so that additional benefits can be accrued. Out of this convergence of waterfront redevelopment opportunity and societal-environmental interest, came the concept of soft shoreline engineering [3,13]. Soft shoreline engineering is achieved by using vegetation and other materials to improve the land-water interface by enhancing ecological features without compromising the engineered integrity of the shoreline.

Soft shoreline engineering is similar to living shorelines for managing coastal erosion, enhancing intertidal habitat for fish and aquatic resources, and enhancing the resilience of coastal communities and ecosystems, climate changes, and extreme climate events [31–33]. The intent is to restore critical ecosystem functions that have been lost due to shoreline hardening. One important distinction that must be made is that rip-rap, as defined as soft shoreline engineering in this study, does indeed interrupt the natural water/land continuum to the detriment of natural shoreline ecosystems. Living shorelines include any shoreline management system that is designed to protect or restore natural shoreline ecosystems through the use of natural elements and, if appropriate, human-made elements [32]. When used at appropriate sites, living shorelines allow for continued coastal processes and ecosystem connections, while also providing shoreline stabilization and habitat.

Three major barriers to broader use of living shorelines and soft shoreline engineering include: institutional inertia; lack of a broader context for shoreline management decisions; and lack of an effective advocate [32]. Strategies recommended to address these barriers include: education and outreach; regulatory reform, especially in permitting; institutional capacity building; and public agencies becoming role models for use of living shorelines.

In 1999, a group of U.S. and Canadian researchers and natural resource managers convened a conference on soft shoreline engineering and developed a best management practices manual [3] to encourage and catalyze use of soft shoreline engineering techniques. That best management practices manual was then used to educate people on the value and benefits of soft shoreline engineering, and to recruit communities, developers, industries, and others to incorporate it in redevelopment and rehabilitation efforts. Essex Region Conservation Authority later developed another manual to help encourage shoreline property owners in Canada to utilize soft shoreline techniques that provide additional ecological benefits [34].

It was clearly understood that soft shoreline engineering would not be feasible at a port facility that wanted to offload freighters or bring in cruise ships. However, where it was feasible, soft shoreline engineering could help achieve many benefits, including reducing erosion and achieving stability and safety of shorelines, enhancing habitat, improving aesthetics, enhancing urban quality of life, increasing waterfront property values, and even saving money when compared to installing concrete breakwaters or steel sheet piling [3,13].

For the purposes of this study, habitat modification means any efforts to conserve, restore, enhance, mitigate, or rehabilitate habitats. This includes soft shoreline engineering projects, incidental habitat projects (i.e., adding habitat features to existing or planned navigational structures like harbor or marina walls, breakwaters, and piers [35]), and steel sheet piling or concrete breakwater replacement projects that utilize limestone rip-rap that provides some habitat features. It is acknowledged that rip-rap is not ideal from a habitat perspective, however, it is better than steel sheet piling and concrete breakwater because it does provide some habitat for fish and other organisms [18–21].

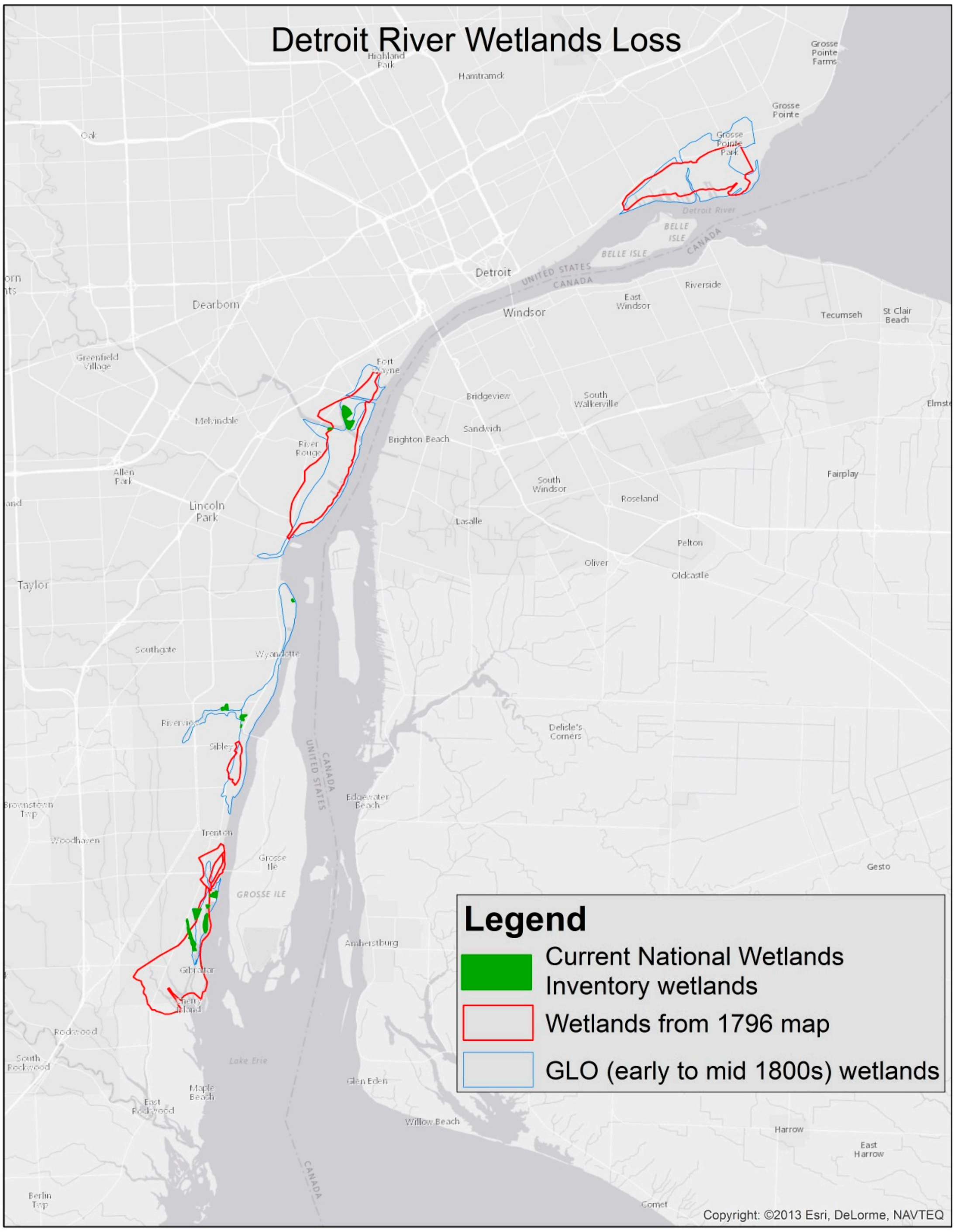

Figure 2. Extent of wetlands loss along the U.S. mainland of the Detroit River (base map credit: map created using ArcGIS® software by Esri (ArcMap 10.4.1)).

Between 1995 and 2016, 19 different shoreline habitat modification projects were completed, representing soft shoreline engineering, incidental habitat, or changing from steel sheet piling or concrete breakwater to some limestone rip-rap that provided some limited habitat features (Table 2; Figure 3). Of these 19 projects, eight were soft shoreline engineering, seven involved converting shorelines to limestone rip-rap to add habitat components, and four provided incidental habitat to structures. Figure 4 provides before and after photographs of two of the soft shoreline engineering projects surveyed in this study.

Based on a review of all soft shoreline-engineering projects in the watershed [36] and this survey, it was important to involve scientists and resource managers during the initial project planning to broaden the scope of shoreline restoration to include ecological goals. All projects were undertaken as demonstration projects to help showcase benefits and encourage other projects. Broadening project partners also helped bring in new funders that leveraged existing funding.

Of the 19 shoreline habitat projects implemented since 1995, 11 had no post-project monitoring, seven had qualitative monitoring, and only one had any quantitative post-project monitoring (Table 2). This problem of limited post-project monitoring could be rectified by: incorporating pre- and post-project monitoring of effectiveness into all federal and state permits for habitat modification; ensuring that any shoreline restoration grants include post-project monitoring; or working with conservation partners to sign a Memorandum of Understanding or a non-binding partnership agreement to perform pre- and post-project monitoring to measure project effectiveness [36].

In total, these 19 projects identified in Table 2 improved 4.93 km of shoreline from a habitat perspective since 1995. The Lake Erie Biodiversity Conservation Strategy is a binational initiative designed to support the efforts of the Lake Erie Lakewide Management Plan by identifying specific strategies and actions to protect and conserve the native biodiversity of Lake Erie [37]. The scope of Lake Erie Biodiversity Conservation Strategy includes the lake itself, the Connecting Channels, including the Detroit River, and the adjacent watersheds to the extent that they affect the biodiversity of the lake. This Strategy developed science-based targets based on a review of existing Great Lakes conservation strategies, scientific assessments of Lake Erie, and input from the project core team, conservation organizations, and other stakeholders. For the Detroit River, the following soft shoreline targets were recommended to provide critical habitats for the full diversity of native species [37]:

- less than 60% soft shoreline—poor quality;
- 60–70% soft shoreline—fair quality;
- 70–80% soft shoreline—good quality; and
- greater than 80% soft shoreline—very good quality.

Table 2. A survey of soft shoreline engineering projects implemented along the U.S. mainland shoreline of the Detroit River, 1995–2016.

Location	Figure 3 Locator	Project Type	Project Goals	Project Description and Cost	Timeframe	Partners	Monitoring
BASF Waterfront Park, Wyandotte, Michigan	1 ●	Rip-rap	Transform a former shipbuilding and chemical manufacturing site (40 ha) along the Detroit River into a public recreation area (called BASF Waterfront Park) and a nine-hole golf course	As part of a $9.1 million park redevelopment and brownfield cleanup, 390 m of shoreline were stabilized and enhanced using limestone rip-rap	Consent Decree signed in 1985; golf course and park opened in 1995	City of Wyandotte, BASF Corp., Michigan Department of Environmental Quality	None
BASF Park, Wyandotte, Michigan	2 ●	Small rip-rap	Demonstrate use of Elastocoast (Elastomeric revetment that stabilizes shorelines and enhances habitat by increasing interstitial spaces) along the Detroit River shoreline of BASF Park	Stabilized nine meters of Detroit River shoreline to a depth of 37 cm with five-cm crushed limestone bound together with the Elastocoast product; $6000	2008	BASF Corporation, City of Wyandotte	Qualitative
BASF Riverview, Trenton Channel, Riverview, Michigan	3 ●	Incidental habitat	Remediate a contaminated site, add incidental habitat to steel sheet piling walls, and create one acre of fish spawning habitat	Following remediation of a brownfield site, incidental habitat was added to 366 m of steel sheet piling, and 0.4-ha of walleye, smallmouth and largemouth bass, and sturgeon spawning habitat was created; $100,000	2007–2008	BASF Corporation, Michigan Department of Environmental Quality	None
Detroit RiverWalk-Stroh River Place, Detroit, Michigan	4 ●	Incidental habitat	Build a section of the Detroit RiverWalk in front of Stroh River Place and enhance riparian habitat	Built a 305-m section of the Detroit RiverWalk using a cantilever design with habitat features beneath the cantilevered RiverWalk; $1 million	2006–2007	Detroit Riverfront Conservancy, Stroh Companies, Inc., Omni Hotel, and Tallon Industries	None
Detroit RiverWalk-West of Milliken State Park, Detroit, Michigan	5 ●	Rip-rap	Stabilize the shoreline along the Detroit RiverWalk and enhance aquatic habitat	Stabilized 152 m of shoreline with varying sizes of rock armor stone and enhanced aquatic habitat; $100,000	2003–2004	Detroit Riverfront Conservancy and General Motors Corporation	None
Detroit-Wayne County Port Authority, Detroit, Michigan	6 ●	Incidental habitat	Enhance fish spawning habitat in conjunction with construction of a 61-m wharf to support Port Authority operations	Enhanced fish spawning habitat through placement of 512 m^3 of limestone rip-rap covering 832 m^2 (64 m by 13 m) at the base of the wharf	2007	Detroit/Wayne County Port Authority, Detroit Riverfront Conservancy	None
DTE's Rouge Power Plant, River Rouge, Michigan	7 ●	Soft shoreline	Remove broken concrete and asphalt, stabilize shoreline, and enhance habitat	Reconstructed 61 m of natural shoreline using soft engineering techniques and reestablished a natural riparian buffer made up of four Michigan native plant communities; $30,000	2005	DTE Energy, Nativescape, U.S. Fish and Wildlife Service, Department of Environmental Quality, and six other partners	Qualitative
Elizabeth Park—Phase 2, South River Walk, Trenton, Michigan	8 ●	Soft shoreline	Stabilize and enhance 183 m of shoreline, recreate river walk, and enhance underwater fish habitat	Removed a 1910 concrete breakwall from the north end of Elizabeth Park, stabilized the shoreline using soft engineering techniques, and created two oxbow islands for nursery habitat for fish; $925,000	2005	Clean Michigan Initiative and Wayne County Parks	Quantitative

Table 2. *Cont.*

Location	Figure 3 Locator	Project Type	Project Goals	Project Description and Cost	Timeframe	Partners	Monitoring
Elizabeth Park—Phase 3, North River Walk, Trenton, Michigan	9 ●	Rip-rap	Stabilize 250 m of Detroit River shoreline, complete the River Walk, and enhance riparian habitat	Graded back the shoreline and stabilized it with Armor stone and landscape plantings, and completed River Walk; $400,000	2012	Michigan Natural Resources Trust Fund and Wayne County Parks	None
Ellias Cove, Trenton, Michigan	10 ●	Soft shoreline	Remediate mercury, lead, zinc, and PCB contaminated sediment from Ellias Cove and restore the shoreline using soft engineering techniques	Removed 88,000 m^3 of sediment and disposed contaminated sediment in special contaminant cell at Pointe Mouillee Confined Disposal Facility in western Lake Erie and restored 270 m of shoreline habitat, including nursery habitat for fish; $150,000 for habitat portion	2006	U.S. Environmental Protection Agency, Michigan Department of Environmental Quality, Great Lakes Basin Program for Soil Erosion and Sediment Control, and seven other partners	Qualitative
Gabriel Richard Park, Detroit, Michigan	11 ●	Rip-rap	Stabilize river shoreline, restore fish habitat, and provide aesthetically-pleasing environment	Stabilized and restored 300 m of shoreline with fish habitat components, including the addition of two fishing overlooks; $300,000	2006–2007	Detroit Riverfront Conservancy, Detroit Parks and Recreation, and JJR	None
Maheras Gentry Park, Detroit, Michigan	12 ●	Soft shoreline	Create an oxbow and restore fish and wetland habitat as mitigation for the construction of Conner Creek Combined Sewer Overflow Control Facility	Removed 38,300 m^3 of soil to create an oxbow, restored 508 m of shoreline habitat, planted native aquatic plants to improve fish habitat, and created fish spawning and nursery areas; $2.3 million	2000–2004	Detroit Water and Sewerage Department and Detroit Parks and Recreation	Qualitative
Mt. Elliott Park, Detroit, Michigan	13 ●	Rip-rap	Restore shoreline using limestone of varying sizes and native plant materials in an effort to help restore fish and wildlife habitat	Restored 200 m of shoreline, including providing an interactive water feature and playscape for children that will teach the importance of water; $200,000 for shoreline habitat work	2012–2013	Detroit Riverfront Conservancy and Detroit Recreation Department	None
Refuge Gateway Shoreline along the Trenton Channel of the Detroit River, Trenton, Michigan	14 ●	Soft shoreline	Stabilize shoreline using soft engineering techniques and restore coastal wetland and upland buffer habitats	Stabilized 365 m of shoreline using soft shoreline engineering techniques and restored 4.2 ha of emergent marsh, 1.7 ha of submergent marsh, and 4.8 ha of upland buffer habitats; $746,000	2010	Wayne County, Michigan Department of Natural Resources, U.S. Fish and Wildlife Service, and six other partners	Qualitative
Refuge Gateway, School Ship Dock and Fishing Pier, Trenton, Michigan	15 ●	Incidental habitat	Enhance fish spawning habitat in conjunction with construction of a 61-m fishing pier	Nearly 418 m^2 of 15–25 cm diameter limestone was placed along a 69 m long × 4.6 m wide fishing pier at a depth of 3–4.6 m to provide spawning habitat and refuge for fish and other aquatic species. Benefiting will be speleophilic (cave spawners) and lithophilic (rock spawners) fish species such as the northern madtom (endangered in State of Michigan and Province of Ontario), lake sturgeon, rock bass, smallmouth bass, and walleye. $100,000	2015–2016	Wayne County, U.S. Fish and Wildlife Service, Great Lakes Fishery Trust, Michigan Natural Resources Trust Fund, CN Rail, DTE Energy, and others	None

Table 2. *Cont.*

Location	Figure 3 Locator	Project Type	Project Goals	Project Description and Cost	Timeframe	Partners	Monitoring
Solutia Plant (now called Eastman Chemical), Trenton, Michigan	16 •	Rip-rap	Stabilize shoreline and enhance habitat	Stabilized 300 m of dike walls on two existing ponds located on the Detroit River using a variety of limestone rip-rap to enhance shoreline habitat (*in lieu* of concrete breakwalls or steel sheet piling); $150,000	2000	Solutia Chemical Company	None
Street-End Parks, Trenton, Michigan	17, 18, 19 •	Rip-rap and underwater fish habitat	Construct three street-end parks and enhance fish habitat to improve fishing opportunities	Created three pocket parks, stabilized 25 m of shoreline at each park (total of 75 m), and rehabilitated habitat in the Detroit River; $816,000	2001–2002	City of Trenton, Clean Michigan Initiative, Michigan Natural Resources Trust Fund, and Michigan Coastal Zone Management Program	None
U.S. Steel Shoreline near 203-cm Rolling Mill, River Rouge, Michigan	20 •	Rip-rap	Restore riparian shoreline habitat using soft shoreline engineering techniques and enhance adjacent upland habitats	Restored 335 m of riparian shoreline habitat (bank stabilization was achieved with large limestone boulders and over 200 live stakes; sand ramps were also created to allow turtles to exit the river and lay their eggs) and 1.9 ha of upland habitat (native wildflowers, shrubs, and trees, and several large snake hibernacula) adjacent to the shoreline; $670,000	2010–2013	Detroit River Remedial Action Plan, Friends of the Detroit River, U.S. Steel, and others	Qualitative
U. S. Steel Shoreline West of Belanger Park, River Rouge, Michigan	21 •	Soft shoreline	Restore shoreline using soft shoreline engineering techniques and enhance fish and wildlife habitat	Restored 610 m of Detroit River shoreline; created wetlands that provide spawning and fingerling habitat, and created an upland buffer area to provide water quality protection; $211,000	2004–2005	U.S. Steel, Nativescape, and U.S. Fish and Wildlife Service	Qualitative

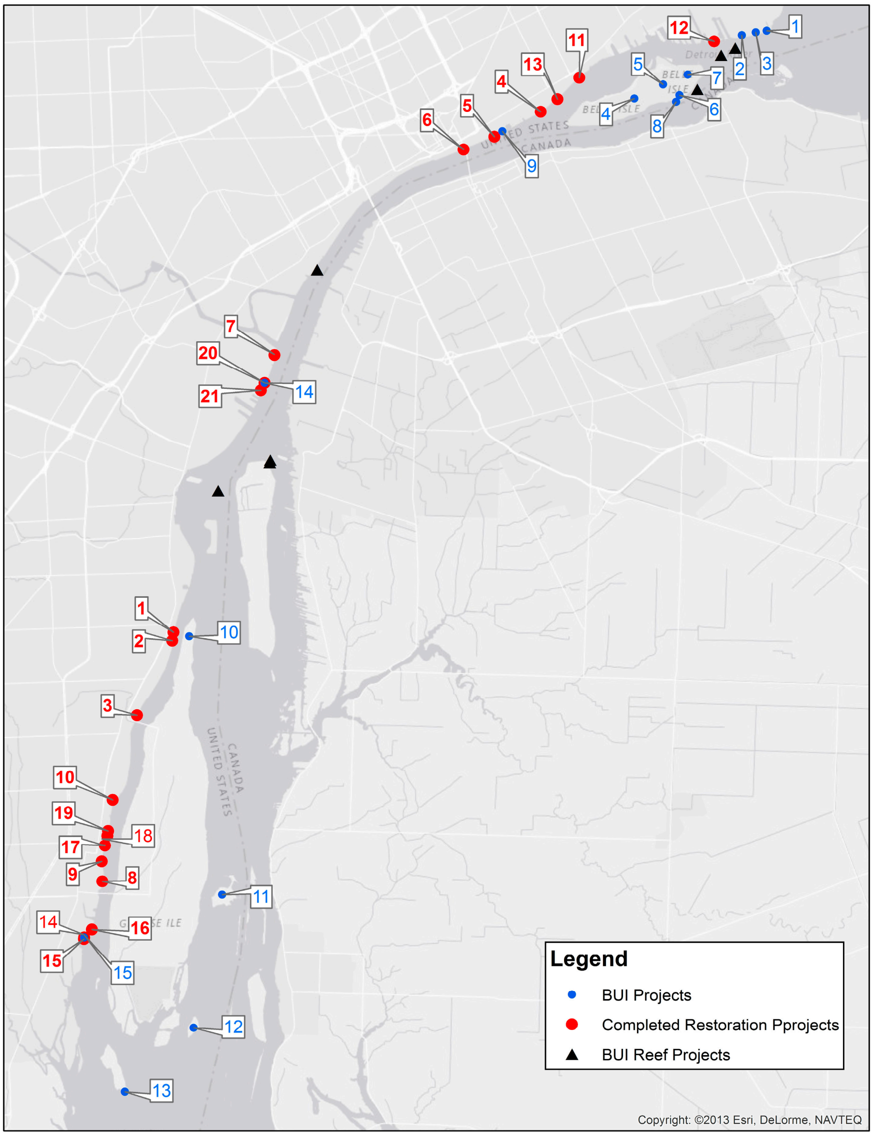

Figure 3. Detroit River map showing locations of soft shoreline engineering projects and 14 Area of Concern projects that, when completed, would constitute removal of "loss of fish and wildlife habitat" as an impaired beneficial use.

(**a**) (**b**)

Figure 4. *Cont.*

(**c**) (**d**)

Figure 4. Photographs of soft shoreline engineering projects at Rouge Power Plant in River Rouge, Michigan ((**a**): before and (**b**): after) and Wayne County's Elizabeth Park in Trenton, Michigan ((**c**): before and (**d**): after) (photo credits: Rouge Power Plant shoreline: Nativescape, LLC (Manchester, Michigan, USA); Elizabeth Park: U.S. Fish and Wildlife Service (Grosse Ile, Michigan, USA)).

A comparison of the 1985 and 2015 georeferenced aerial imagery showed that 2.32 km of soft shoreline was converted to hard shoreline (Figure 5). Of the 19 projects surveyed in Table 2, 11 projects representing 3.35 km made habitat improvements to Detroit River shoreline that was already georeferenced as "soft", three projects representing 360 m of shoreline were converted from "hard' to "soft", and five projects representing 1.22 km added incidental habitat to a hardened shoreline. It is interesting to note that one of the projects that converted from "soft" to "hard" shoreline was the BASF Riverview project that installed steel sheet piling to maintain an inward hydraulic gradient to prevent input of contaminants to the river from a brownfield site. As part of this brownfield cleanup BASF also added 366 m of incidental habitat at the base of the sheet pile wall, along with 0.4 ha of walleye, largemouth bass, and sturgeon spawning habitat in the river. Habitat experts advocated for this as part of the remedial design.

Figure 5 shows that even with the addition of 1.58 km of new soft shoreline and incidental habitat, there was an overall net loss of 0.74 km of soft shoreline over the 30-year timeframe. This confirms that shoreline hardening continues despite the best efforts of resource managers and conservation organizations. The reasons for this include lack of proper training among planners and designers, lack of "habitat champions" at design phase of urban waterfront redevelopment projects, and the perceived risks associated with alternatives to hard engineering. This also points out a need for continuous and vigorous oversight of shoreline development projects to ensure long-term shoreline habitat goals can be met. To reach the "good" state of at least 70% soft shoreline, an additional 12.1 km of soft shoreline would have to be added in the future.

Most of these shoreline habitat projects in Table 2 were undertaken opportunistically through a variety of management tools to enhance/improve riparian or aquatic habitat, including: erosion protection; nonpoint source pollution control; Supplemental Environmental Projects (i.e., a regulatory tool that implements an environmental improvement project instead of paying fines and penalties to a general fund); contaminated sediment remediation; improvement of waterfront parks; enhancement of private developments; and greenway trail projects. However, there is also a need to move beyond opportunistic habitat rehabilitation and enhancement, and achieve scientifically defensible, ecosystem-based management. This will require greater identification, quantification, and understanding of essential habitats as a prerequisite to successful management of target species and assemblages. Lack of scientific understanding and institutional problems have been identified as major impediments to scientifically defensible management of coastal habitats [38]. Clearly, it has been an enormous management challenge to shift from managing species/assemblages to managing habitats to support species/assemblages, particularly in an environment of limited resources for research and management infrastructure [38].

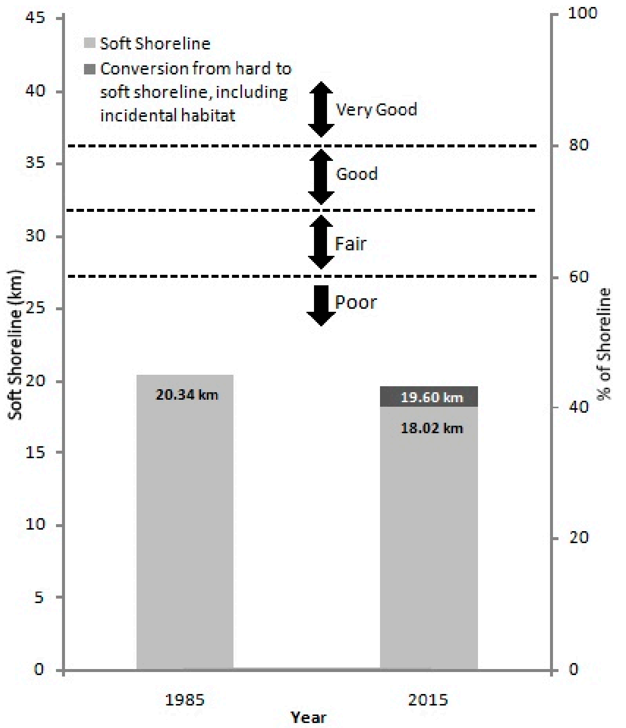

Figure 5. A comparison of the extent of soft shoreline along the U.S. mainland of the Detroit River as measured by georeferenced aerial imagery, 1985 and 2015.

Actions to rehabilitate and enhance degraded habitats should be based on the understanding of causes and predicted results [38]. Adequate assessment, research, and monitoring are essential to define problems, establish cause-and-effect relationships, evaluate habitat rehabilitation and enhancement options, select preferred rehabilitation and enhancement techniques, and document effectiveness. It has been recommended that resource management agencies, with stakeholder input, should identify desired species, then quantify the amount and quality of habitats required to produce and sustain each species by life history stage [39]. Once this collective knowledge is obtained, quantitative habitat targets can be established, habitat management options reviewed, and the preferred actions selected. After implementation of the preferred actions, it is recommended that monitoring be performed for at least five years to ensure that the quantitative habitat targets are met and that the restored habitats remain protected and productive [39]. Such monitoring would also allow for implementing additional habitat management actions consistent with adaptive management that calls for assessing status, setting priorities, and taking actions in an iterative fashion for continuous improvement. It is recognized that much longer-term monitoring will be required to reach and document a new equilibrium.

For over 30 years the Michigan Department of Environmental Quality and the Public Advisory Committee for the Detroit River Area of Concern (i.e., a pollution hotspot in the Great Lakes where there is impairment of beneficial uses) have been working to restore impaired beneficial uses in the Detroit River Area of Concern as part of the U.S.-Canada Great Lakes Water Quality Agreement [40]. To guide restoration efforts, the Detroit River Public Advisory Committee has identified 14 projects that, when completed, would constitute removal of “loss of fish and wildlife habitat” as an impaired beneficial use (Table 3; Figure 3).

Table 3. Fourteen projects identified by the Detroit River Public Advisory Committee that, when completed, would constitute removal of "loss of fish and wildlife habitat" as an impaired beneficial use [41].

Delisting Project	Figure 3 Locator	Brief Description	Status
Detroit River Reefs	▲	Construct fish spawning reefs for native fishes at six locations	Two fish spawning reefs off Belle Isle, two off Fighting Island, and one off Grassy Island constructed in 2004–2016, totaling 4.05 ha; one additional 0.93-ha reef to be constructed in 2017
Detroit Upper Riverfront Parks Restoration	1, 2, 3 •	Restore shoreline habitat at Mariner Park, Lakewood East Park, and A.B. Ford Park	In design phase
Belle Isle Hydrologic Analysis, Feasibility and Pre-Design	4 •	Investigate the waterways of Belle Isle in order to effectively design the habitat restoration projects in the Belle Isle forested wetland and Lake Okonoka	Underway
Belle Isle Forested Wetland Restoration	5 •	Restore approximately 81 ha of wet-mesic flatwoods complex and adjacent habitat	Underway
Lake Okonoka Restoration with River Connection and Shoreline Restoration	6 •	Enhance habitat for birds, fish, amphibians, and reptiles	Underway
Milliken State Park Pocket Marsh with River Connection	9 •	Create a naturalized area of nearshore, protected, shallow water habitat and shoreline with direct connection to the Detroit River	In design phase
Hennepin Marsh Restoration	10 •	Protect and enhance the existing submergent wetlands and create additional emergent wetland	Not started
Stony Island Shoal Reconstruction	11 •	Restore 610 m of shoals to protect the island from further degradation of existing wetlands, and provide an environment for the natural regeneration of additional wetland habitat over time	Started in 2016 and to be completed in 2017
Sugar Island Restoration	12 •	Stabilize the island and restore fish and wildlife habitats	Not started
Celeron Island Restoration and Shoal Construction	13 •	Prevent further degradation to the southern end of the island by constructing shoal system and concurrently enhance fish and wildlife habitat	In design phase
Blue Heron Lagoon Restoration	7 •	Reconnect and naturalize the connection between Blue Heron Lagoon and the Detroit River, restoring fish access to over 16 ha of existing wetlands, shallow and deep-water habitat and over 3.5 km of canal habitat, including coastal wetlands specifically designed for fish rearing and nursery habitat	Completed in 2013
Belle Isle South Fishing Pier Restoration	8 •	Increase fish populations by providing connectivity between fish spawning and nursery areas in the river by creating 1 ha of wetlands immediately downstream of an existing spawning reef and creating deep and shallow water habitats in the flat bottomland of the pier	Completed in 2013
U. S. Steel Shoreline Restoration	14 •	Restored 335 m of riparian shoreline habitat and 1.9 ha of upland habitat adjacent to the shoreline	Completed in 2013
Shoreline Restoration at Wayne County's Refuge Gateway	15 •	Stabilized 365 m of shoreline using soft shoreline engineering techniques and restored 4.2 ha of emergent marsh, 1.7 ha of submergent marsh, and 4.8 ha of upland buffer habitats	Completed in 2010

Completing these Detroit River Area of Concern projects and achieving these administrative/management targets will clearly have a positive impact on habitat of the Detroit River. However, it will also be important to track progress and eventually achieve ecosystem-based targets like the percentage and length of soft shoreline presented above. Such ecosystem-based targets will help measure ecological progress and are consistent with the U.S.-Canada Great Lakes Water Quality Agreement. Indeed, researchers have argued for inserting evidence-based management into conservation practice, including quantitative outcome-based monitoring toward clear measurable objectives [42].

5. Concluding Remarks and Outlook

As a result of the 97% loss of coastal wetlands along the U.S. mainland of the Detroit River (due to urban and industrial development) and the hardening of 55% of the U.S. mainland shoreline with steel sheet piling or concrete breakwater by 1985, partnerships were formed to rehabilitate shoreline habitat to restore fish and wildlife populations, and to achieve benefits from the additional ecosystem services this habitat would provide. Similarly, there has been a 95% loss of coastal wetlands on the Canadian mainland of the river and 80% of the Canadian shoreline has been developed as a result of urbanization, with the majority of the shoreline being artificially hardened [43].

Since 1995, 19 projects were implemented improving 4.93 km of shoreline habitat. A comparison of the 1985 and 2015 georeferenced aerial imagery showed that 2.32 km of soft shoreline was converted to hard shoreline during this timeframe. Of the 19 projects surveyed, 11 projects representing 3.35 km made habitat improvements to shoreline that was already georeferenced as "soft", three projects representing 360 m of shoreline were converted from "hard' to "soft," and five projects representing 1.22 km added incidental habitat to hardened shoreline. Even with the addition of 1.58 km of new soft shoreline and incidental habitat, there was an overall net loss of 0.74 km of soft shoreline over the 30-year timeframe. To reach the "good" state of at least 70% soft shoreline, an additional 12.1 km of soft shoreline will have to be added in the future. This confirms that shoreline hardening continues despite the best efforts of resource managers and conservation organizations, and that there must be continuous and vigorous oversight of shoreline development projects to ensure long-term shoreline habitat goals can be met.

Restoring shoreline habitat along the Detroit River will clearly be a long-term process, with incremental progress. As urban waterfront redevelopment progresses, it will be important to be opportunistic and involve habitat experts up front in the design phase because experience in metropolitan Detroit has shown that it is at the design stage where key decisions get made. At the outset of new urban waterfront development projects it will also be important to establish broad-based objectives for shoreline engineering with quantitative targets for project success, and to ensure sound multidisciplinary technical support throughout the project.

Urban river shoreline restoration will undoubtedly progress following adaptive management. For management organizations interested in restoring shorelines of urban rivers it is recommended to:

- encourage federal and state regulatory agencies to promote soft shoreline engineering through permitting processes and if hard engineering is essential for port operations, marina development, or residential development, these agencies should encourage incorporating incidental habitat [35,44];
- start with demonstration projects and attract many partners to leverage resources;
- treat habitat modification projects as experiments that promote learning, where hypotheses are developed and tested using scientific rigor;
- involve citizen scientists, volunteers, university students, and/or researchers in monitoring, and obtain commitments for post-project monitoring of effectiveness up front in project planning;
- measure benefits and communicate successes; and
- promote education and outreach, including public events that showcase results and communicate benefits [36].

Much like the sustainable development efforts to recreate front porches on city houses to encourage a sense of community, soft-engineered shorelines along urban waterfronts can help recreate gathering places for both wildlife and people.

Acknowledgments: This manuscript would not be possible without the leadership of the many soft shoreline engineering partners who catalyzed and completed the 19 projects discussed in this manuscript. We gratefully acknowledge their important work that laid the foundation for this manuscript.

Author Contributions: Hartig J. and Bennion D. conceived and performed the GIS analyses and the soft shoreline survey, and wrote this paper.

Conflicts of Interest: The findings and conclusions in this article are those of the author(s) and do not necessarily represent the views of the U.S. Fish and Wildlife Service.

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