COASTAL CITIES IN A CHANGING CLIMATE

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COASTAL CITIES IN A CHANGING CLIMATE

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EDITORIAL
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Editorial: Coastal Cities in a Changing Climate

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Editorial on the Research Topic

Coastal Cities in a Changing Climate

In recent years, we have found ourselves apologizing to students for the failures of earlier generations, including our own. We were each taught about climate change, albeit it in rudimentary terms going back in some cases to the early 1970s, and relayed that message to students and young researchers since the 1980s. Yet, here we are with COP26 in the rear view mirror and rising public awareness of the realities of climate change, but with little real accomplishment in terms of driving down greenhouse gas emissions.

The science of climate change has made profound advancements since the 1980s. Examples include our ability to collect and analyse environmental data, model future trends, and deploy machine learning and powerful visualization techniques. Additionally, emerging technologies allow much greater energy efficiencies at all scales. Alternative energy, including wind and solar, have also experienced major improvements.

Despite these technical advances, coastal cities still face increasing risks due to our inability to put these accomplishments into widespread use. For centuries, urbanization has concentrated in coastal regions where marine resources sustained population centers, where maritime trade opportunities thrived, and in recent years where amenities lured ever increasing numbers of people toward the shore. Many cities with millions of residents line the littoral lands around the globe. These cities, their residents, and economies are at the doorstep of the impending climate-driven sea-level rise we have been hearing about for decades. Some are already experiencing increasing impacts from more violent weather and blue-sky flooding.

Much of the climate change science has concentrated, rightly, on the processes of global warming, the impacts to ocean chemistry and currents, to atmospheric circulation, and to the melting of glaciers. It is essential to grasp the pace and extent of these interrelated processes. Where climate change inquiry has lagged, has been in the social and cultural arenas. How will place-based cultures adapt to slow moving environmental change? How will risk cultures incorporate an understanding of the newly emerging challenges? How will governance systems respond to the science and the changes to those they govern? How will societies adapt existing coastal protection systems to previously unknown conditions? How will countries deal with the dislocation of coastal populations? How will societies and governing bodies deal with the narrowing range of options as change proceeds? These questions must draw on the humanities and social sciences—the areas of academic expertise dedicated to such topics. In recent IPCC assessments, and the last two decades, there has been much more attention focused on these kinds of questions, with important contributions from the social sciences and humanities. However, these questions are far from fully answered.

The papers in this special topic of *Frontiers in Science* arose from a workshop on Coastal Cities hosted by Shanghai University Center for the History of Global Development in 2019 (Global

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Environment, 2021). The organizers sought to bring together scholars from around the world to explicitly consider the place of society and culture in transforming the environments of coastal sites into major cities and how human-initiated environmental change in the creation of cities provides a foundation for adapting to current environmental change. Also, they sought to foreground how the social and cultural processes that occurred over centuries provide insight into current responses to increasingly turbulent storms and rising sea levels. These processes are deeply rooted in beliefs, attitudes, and values that shape how societies face risk and respond to change.

The biggest challenges we face today with climate change is not understanding the science—although much remains to be understood—but mobilizing the myriad social and cultural institutions to act in a coordinated way. Traditional science approaches alone cannot bring us to a unified transition aimed at a sustainable future. These papers scratch the surface of that challenge by starting with questions about the human role in dealing with environmental change in coastal settings. Planners, geographers, historians, and a range of scientists pose critical questions about how government institutions and public policies have altered coastal environments and how they have changed their approaches over time. Authors probe the role of risk culture in shaping adaptation to changing conditions and how that modifies mitigation projects in littoral regions. Such adaptations produce long-lasting infrastructure that becomes an impediment to subsequent adaptations and consequently prompts alterations in governance. Relocation is a major component of the coastal cities challenge and attachments to place and locally based natural resource economies defy simple plans to resettle threatened communities. Financing adaptation further complicates matters. It is not just a matter of economics, imposing accountability on those who created maladaptive practices in the past can prompt social conflicts. Increasing risks can narrow the adaption options, but culturally conservative communities may be slow to respond to heightened risks that are largely imperceptible in daily life. Each article underscores how societies and cultures are dynamic and have purposefully imposed their will on the environment, and also reacted to past environmental change in dramatic ways. The resulting complex and dynamic social processes are magnified in the most urbanized areas with low lying coasts and huge populations. To enable viable responses requires more than science.

Scholars from the social sciences and humanities have been urging their colleagues to speak more directly to the scientists who have led the climate change inquiries. Now more than ever, there are compelling reasons to foster an exchange and to expand collaborations that tap the expertise of humanities scholars and social scientists. While a truly unified response might be a fanciful notion, by understanding how societies and place-based cultures cope with environmental change we stand a better chance of summoning a more coherent response to the threats faced in coastal cities, and to the opportunities that lie in these places and their communities to chart new pathways towards transformative climate resilient development.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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ORIGINAL RESEARCH
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Wetland Governance: Contested Aspirations and Reflexive Roles of Local Professionals Toward Worlding Cities in Tai Lake Basin

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This paper examines the contested agendas generated by Tai Lake Basin's (TLB) recent wetland constructions and how these dynamics have stimulated the particular aspirations concerning nature among various local actors. Through interviews with local ecologists, landscape architects, and environmental engineers, this paper details how they convergently subscribe to the ethical claims of humans and nature during the decision making in constructing wetlands. I termed these dynamic considerations as 'Ecological Governmentality.' Under the influence of environmental conservation as a global consensus, the idea of 'wetland' has regained prevalence among Chinese cities' plans and policies in recent decades. In the TLB, one of the most developed regions in China's southeast coastal areas, over 800 'wetland parks' have been established. Situated in the basin context, this paper further problematizes three modalities of wetland construction in the case of Suzhou city, namely: National Certificated Wetland Parks propelled by international environmental conservation agendas, Urban Wetland Landscape Parks associated with urban redevelopment, and Engineering Constructed Wetlands generated by the opening niche market for municipal waterworks. The construction of these parks has made prominent attempts to rewild urban environment through re-territorialization, design, and technology innovations intersected with moral claims that go beyond pure scientific concerns of ecology. Building on the concept of 'worlding practices' and 'governmentality,' three cases in this paper illustrate how the mainstreaming of wetlands in Suzhou has been materialized along with the shared notion of city branding from global neoliberal urbanization. More specifically, this paper explores the diverse materialization through the lens of contested ethical aspirations and transferred roles taken by different actors in the local wetland governance. The emerging 'Ecological Governmentality' in wetland construction helps to consolidate the unique ecological imaginary in China and diversify the Chinese cities' globalization in the making.

Keywords: ecological governmentality, wetland conservation, environmental governance, ecological imaginary, globalization, landscape design, moral ecology, Suzhou

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INTRODUCTION

Recent decades have witnessed rapid urbanization on a global scale. The side effects of the increasing number of unregulated development have threatened the environment and ecological capacity. Since the first image of the earth[1] was taken in 1972, the anxiety of environmental conservation has become a global discourse that totalizes human behaviors in the living environment, as we are now in 'a Community of Human Destiny' (Franklin et al., 2000). China, as a fast-developing country, on the one hand, is responding to the fragmented human-nature relationship through a series of reformative environmental practices such as eco-cities, green buildings, and wetlands conservation in developed coastal cites (Li et al., 2014; Sze, 2015; De Jong et al., 2018). On the other hand, these practices are also linked with the competition to build 'world cities,' in which a good environment becomes a city asset able to attract outside investments (Goldman, 2011). While many scholars have focused on the techno-scientific aspects of these practices and the injustices in middle-class environmental ideology (Yeh, 2009; Pow, 2018), few studies have scrutinized the contingent role of local actors in delivering these central projects to local contexts, especially for the recently proliferated wetlands in Chinese cities. Wetlands are critical resources of coastal cities that suffer from climate change and urban development. Its adaptation demands locally based governance which not only relies on science rationales but also human dynamics. Therefore, this paper focuses on the conservation and construction of wetlands in the Tai Lake Basin (TLB) after the proposals made for ecological civilization[2] in China in 2007. The individual aspirations and reflexive roles of local experts in building new wetlands will be reviewed. Wetlands as a shared milieu that is undergoing constant ecological imaginaries and is currently mobilizing different local actors in China.

Asia's Worlding City Practices

The growing value of environmental resources, along with urbanization, is significantly influenced by the developing discourse on globalization. The early hypothesis of globalization developed by Friedmann and Wolff (1982) highlights the notion that global cities are local territories, set up for political and historical reasons to accumulate global capital. When extending attention from social-political influences to environmental consequences, Checker (2011) worries that recent globalization with neoliberal capital will inevitably lead to 'environmental gentrification' where the monotonous urban landscape is generated from top-down forces in order to fit middle-class environmentalism. However, Olds and Yeung (2004) are skeptical about the typical dichotomy between global and local. While market rationalities have gradually played an essential role in current environmental projects, they are not necessarily materialized in the same way as they have been by superior powers. Instead, as Roy and Ong (2011) have described in their book *Worlding cities: Asian experiments and the art of being global*, Asian cities tend to have their own norms toward being global rather than merely copying forms from early western models.

Moreover, the key to that term 'Worlding Practices,' resonating with the discussion of globalization in Chinese cities by Wu (2006), lies in the local contingency brought by specific history and cultures of both the collective and individuals. More specifically, different local actors aim to separate from established urban protocols by reinventing worlding–conjuring projects in their own assembled ways, which sheds light on the neglected aspects of globalization (Ong, 2011). Therefore, building on the idea of contextualized globalization, this paper uncovers the potential of wetland construction in TLB as a 'Worlding Practice' through which local actors such as ecologists, landscape designers, and environmental engineers are contested to reshape the local environment and contribute to the Chinese cities' globalities in the making.

Ecological Governmentality in Modern Wetlands Construction in China

Ecology is the topical concept in the current practice of wetland conservation and construction. The definition of ecology can be traced back to its Greek etymology[3]: the study of the place in which we dwell by German scientist Ernst Haeckel (Bowker, 2005). Ecological thoughts, thus, cannot be separated from the broad discussion of human social interaction, which is reflected in ethics and politics. However, modern ecology became a much more rigorous science in the late 19th century, which focuses on the evolutionism of organisms, biophysical environment, and their interaction together as ecosystems (Worster, 1994). The discussion of ecology is closely related to urbanization, such as the popularization of ecological restoration after the 1980s. Various projects, especially wetland conservation and management, have been set up with the aim of recovering the degraded ecosystem brought by human activities (van Der Heijden, 2005). The United States has developed an advanced wetland banking mechanism[4] to compensate for the wetland lost off-site due to commercial development (Robertson, 2004). In the Netherlands, the restoration of the wetland ecosystem has been legalized with the crucial river basin management through water framework directive (WFD; Coops and van Geest, 2007). Nevertheless, ecology is still an ambiguous term which is understood differently in each wetland project. The approaches to replication, rehabilitation, or regeneration depend on the aim set up by practitioners, which not only from ecological factors but also economic, social, cultural, political, and moral factors (Higgs, 2003).

[1]The Blue Marble is the first complete Photograph of Earth taken by the crew of the Apollo 17 spacecraft on its way to the Moon.

[2]Ecological Civilization was first proposed in 2007 and has becomes the predominant environmental discourse in China, especially after 18th National Congress of the Communist Party of China in 2012. For more information, please see Zhang et al. (2007).

[3]Ecology = 'oikos' + 'logy.' Oikos refer to house or dwelling places while logos refer to the truth.

[4]Wetland banking belongs to the mitigation banking, which is a market system of credits and debits devised to balance the ecological loss in a broad perspective.

The ambiguous definition and unpredictability of ecology create challenges to wetland governance. The existing governance of wetlands, as well as many other sustainable projects in China, has been decentralized mainly to the municipal level with multiple actors involved since opening reforms in the late 1980s. The highest level of administration of wetlands comes under the State Forestry Administration, which is responsible for the national wetland resources. This body sets up and audits three spatial levels of wetland conservation in China, namely: natural wetland reserves of China[5], certified wetland parks[6], and wetland protection districts[7] (State Forestry Administration, 2013). However, the implementation of conservation and the construction of wetlands are all decentralized into the Municipal Forest Bureau, in order to reduce the central government's financial pressures and stimulate the initiative of the local authorities.

Although decentralization can give more flexibility for adapting wetland governance to local contexts, it also poses challenges between what has been planned and what is the reality on the ground. The deficiency of national wetland law and the broad international definition[8] of wetlands means that wetlands have become a panacea to urban problems. Except for the three spatial levels concerning the conservation of national wetlands, different types of wetlands have emerged at localities. For instance, while large scale wetland reserves have been established to rescue the degrading lake ecosystem (Halls, 1997), small scale artificial wetlands have also been constructed to collect rainwater or purify the water in rivers (Shutes, 2001). Moreover, the mainstream of wetland constructions also leads the existing research of wetland governance in China, which is primarily focused on the techno-scientific and managerial dimensions, such as water quality indicator assessment, technological applications, and wetland parks' design and planning (Bai et al., 1999; Yang et al., 2008; Pan et al., 2010; Cronk and Fennessy, 2016). The governance dimension that involves contested mentalities and conflicts of individual actors has seldom been elaborated.

Governance is not only a 'take for granted' multi-stakeholder administration but is also about the dynamic power politics among local actors and self-government. Foucault in the 1990s, developed the idea of governmentality, which expands the network of governing to the focus of how the population themselves can internalize a particular regime of practices (Foucault, 1991). Certain mentalities or regulations are easy to reach collectively with the consideration of optimal functioning of society and individual happiness (Rose, 1996). Dean (2010) further develops the governmentality into an analytical framework that consists of studying practices of authorities and techniques, as well as the identities and aspirations of individual actors.

Pellizzoni (2011a) further links the notion of governmentality to understanding the mainstream practices of 'neoliberalism of nature.' It was the idea initially identified mostly by neo-Marxists, which refers to the management of natural resources based on market logic (McCarthy and Prudham, 2004). However, it is different from classical liberalism, which thinks nature is a material that is constrained by overpopulation and economic growth. Neoliberal discourse conceives nature as a persistent existence that can be manipulated by technologies to grow limits (Lemke, 2003; Fuller, 2008). Thus, by using neoliberalism of nature, the state is not only off-loading its power to the private sector, society, and individuals but is also stimulating the economy as a collective mentality (Castree, 2008; Adams et al., 2014).

Some of the increasing local actors in environmental politics are experts. In China's wetland projects, experts are usually people with expertise in ecology and the environment. From literature, different arguments have been developed in the debate of expertise on environmental problems. Experts have been traditionally sought as the representation of neutral science. They speak truth to power, which improves the effectiveness and reliability of policies (Wildavsky, 1979; Ezrahi, 1990; Pellizzoni, 2011b). However, with the complexity of environmental problems in modern society, our knowledge of the environment and ecology are differentiated. Expertise is proliferated to become a knowledge commodity sold to the government, which is tailored with particular values (Pellizzoni, 1999; Sarewitz, 2004; Maasen and Weingart, 2005). Science adapted in policymaking is often subject to various constraints such as political-oriented problem defining and purpose-led data selection (Hausknost, 2014). As a response, Brown (1997) and Fischer (2000) propose the 'lay-local knowledge' where specialists and non-specialists jointly address environmental issues, while counter-expertise also rise among activists to provide grassroots alternatives to scientific solutions (Yearley, 2005; Rootes, 2007). Therefore, expertise is gradually becoming politicized and the terrain of conflicts. Policies and Technologies, supported by 'facts,' intertwine subtlety with the politics of interests and values from experts (Pellizzoni, 2011b).

This article intends to disclose the contested local wetland governance through the lens of individuals' aspirations. As a preliminary study of the larger dissertation project, this paper focuses on one of the cities in TLB (Suzhou) from the lens of local experts. Three emerging wetland cases are investigated: Sanshan Island National Wetland Park, Suzhou Zhenshan Park, and Zhujin Central River Wetland. For each case, qualitative analysis has been conducted on the extent to which the particular history and culture affect the individual actors' aspirations to wetlands, and also how these are materialized in the everyday languages, planning drawings, and instruments. 'Ecological governmentality' is reflected in these intangible transformations. For instance, the findings through interviews and content analysis suggest that three actors (ecologists, landscape designers, and environmental engineers) are the leading actors in local

[5]Wetland natural reserves, resonate with general notions of natural reserves, and aim to build a natural genetic data base for precious species with strictest protecting actions, largest spatial scale, and state investment.

[6]Based on the biodiversity value, it aims to diverse the ecological services of wetlands mainly though eco-tourism discourse.

[7]They are minor spatial managed areas acting as a spatial bond between scattered Wetland Natural Reserves and Certificated Wetland Parks. They are mainly identified by local authorities' aspirations.

[8]Origin as an ecosystem concept in ecology study, wetlands usually refer to a natural or artificial area with marsh or water where the depth of water during low tide reaches a minimum of six meters. From the Ramsar definition of Conventions on wetlands in 1971. For more information https://www.ramsar.org/about-the-ramsar-convention.

wetland construction. They are not only delivering wetlands from the level of central to local but also reflexively transferring their roles in local wetland governance. The transformation is mobilized by particular ethical claims on humans and nature and is deeply influenced by different disciplinary cultures and personal experiences.

HISTORICAL BACKGROUND ON WETLAND TRANSFORMATION IN THE TAI LAKE BASIN

Wetlands have been part of the vital landscape in TLB throughout history. On a larger geographical scale, TLB is a natural wetland habitat that was formed some 40 million years ago. TLB is located downstream of both the Yangtze River and the Qiantang River and flows toward the China East Sea. The collective sediment deposition of the two rivers formed the early TLB (Xia, 1979). The low-lying topography, with a shallow freshwater lake in the center and dense river network surrounding, provides a natural mediation of surrounding regions (**Figure 1A**). The water entering from the western Tianmu Mountain restores Tai Lake with hundreds of swamps as well as flourishing reeds. The water then flows out to the eastern rivers running toward Suzhou and Shanghai. On a medium scale, the traditional dike-pond system, as a productive landscape, also served as an early artificial wetland in the rural areas of TLB. The convergence of water-rich geography and the mild climate serves to shape the classical cultural identity of TLB, which is known as the 'Jiangnan water town,' a name that reflects the prosperous scenarios of the place in terms of harvested fish and rice.

During the last 30 years, the fast industrialization and agricultural development in this region has caused the degradation of the natural wetland system. Severe flooding risks have stimulated the engineering water conservancy projects in the basin. The regional authority[9] started the 11 Backbone Works of the Tai Lake in 1987. The plan aims to defend, control and drain away from the flooded water in the quickest way through the building of elevated dikes and water gates and by widening drainage channels, etc. Eleven hydraulic engineering-based projects have significantly reduced the number of swamps in the basin. Many wetlands have been reclaimed into the built lands, and the soft (natural) edges of the lakes and rivers have been straightened. These 'hard' hydraulic engineering-based projects have sustained and become the dominant approaches of modern water governance in TLB since the early 21st century.

The necessity of revitalizing the wetland landscape in TLB is utmost importance given the algae bloom outbreak in 2007. This catastrophe in the summer of that year left Wuxi city with a lack of freshwater supply for 2 days. Some parties speculated on the price of bottled water, and people started to escape from the city. The environmental crisis catalyzed the rethinking of water management. The former water quantity control has since been adjusted to a quality restoration that is focused on nutrient levels and biodiversity in the whole ecosystem. A series of plans concerning the revitalization of the natural environment of TLB has been established (National Development Reform Commission [NDRC], 2008). The most significant change is the re-naturalization of the waterfront in Tai Lake. This was verified by an elderly resident living nearby. In his comment, 'I can see that those reeds are coming back.' Indeed, local governments around Tai lake have started several Ecological Embankment Reconstruction Projects that aim to recall the 'historical wetland landscape' by changing existing vertical hard dikes into slopes with replanted aquatic plants such as reeds (Ni and Zhao, 2008; Jiangnan Evening Newspaper, 2018; China Natural Resources Newspaper, 2019). Furthermore, as **Figure 1B** shows, over 800 wetland parks' have been competitively established in the eight cities of TLB.[10] Wetlands have regained prevalence among municipalities' development plans because of the assemblage of green aesthetics, ecological benefits, and water treatment ability (Zhao et al., 2005). However, the vague definition and lack of legislation on wetlands have led to different actors subscribing to the ecological rationale through divergent 'wetland' constructions.

CASE STUDY SELECTION AND METHODOLOGICAL APPROACH

This paper focuses on Suzhou city in TLB with three contemporary wetland projects (Sanshan Island National Wetland Park, Suzhou Zhenshan Park, and Zhujin Central River wetland) as the primary case studies. Suzhou is graphically located at the center of TLB, which now constitutes two-thirds of Tai Lake water surfaces and management. The city is known as a historical water town with 21 canals and 314 bridges dating from the Song dynasty, and 40% of existing lands are wetlands (Breitung and Lu, 2017; Suzhou Wetland Protection Management Station [SWPMS], 2019). Except for the rich water heritage, Suzhou is also economically prosperous compared to other cities in TLB. Although Suzhou is a prefecture-level city that joined the modern global network with the overflow effects of Shanghai in the 1990s, it is now the second biggest city in the TLB with a population of over ten million and attracting US$132 billion in Foreign Direct Investment (Suzhou Municipal Government, 2019; Ren, 2020). The growing economy, intertwined with the deeply rooted water culture, has stimulated the endeavor for the city government to plan a Healthy Ecological Wetland City. It has since become the first Prefecture level city in China to legitimize the wetland governance (Suzhou Forestry Bureau, 2016). However, the plan is now mainly focused on strategic planning and demonstration projects with few comparative overviews and reflections. Therefore, in-depth understanding through case studies can shed light on the politics behind existing wetland mainstreaming.

The first case, Sanshan Island National Wetland Park, is one of the first generation of national certified wetland

[9]Taihu Basin Authority is the current watershed governance institution. For more information please see http://www.wujiangtong.com/webPages/DetailNews.aspx?id=15206.

[10]The outcomes were from google search of keywords 'Wetland Park.'

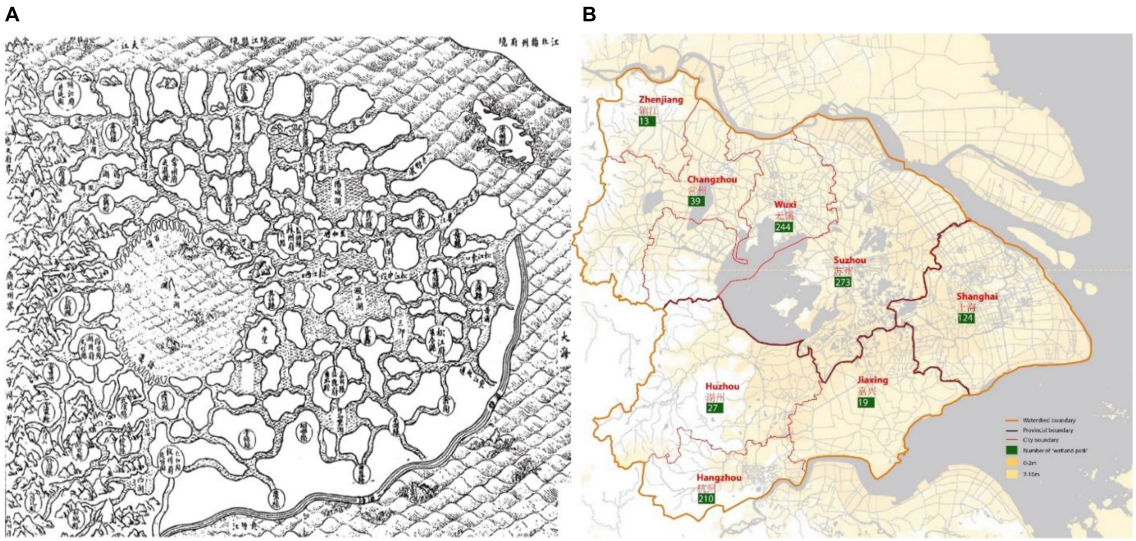

FIGURE 1 | Historical transformations of Tai Lake Basin (TLB). **(A)** Map of seven prefectures of Southeast China showing the 'soft edge' archipelago water morphology and lougang (dike-pond) around Tai Lake (Source: Zhang, 1639). **(B)** Existing jurisdiction plan and numbers of 'Wetlands Parks' on the low-lying typography of TLB (Source: data from the google map searching with a based map that was adapted from Nolf et al., 2020).

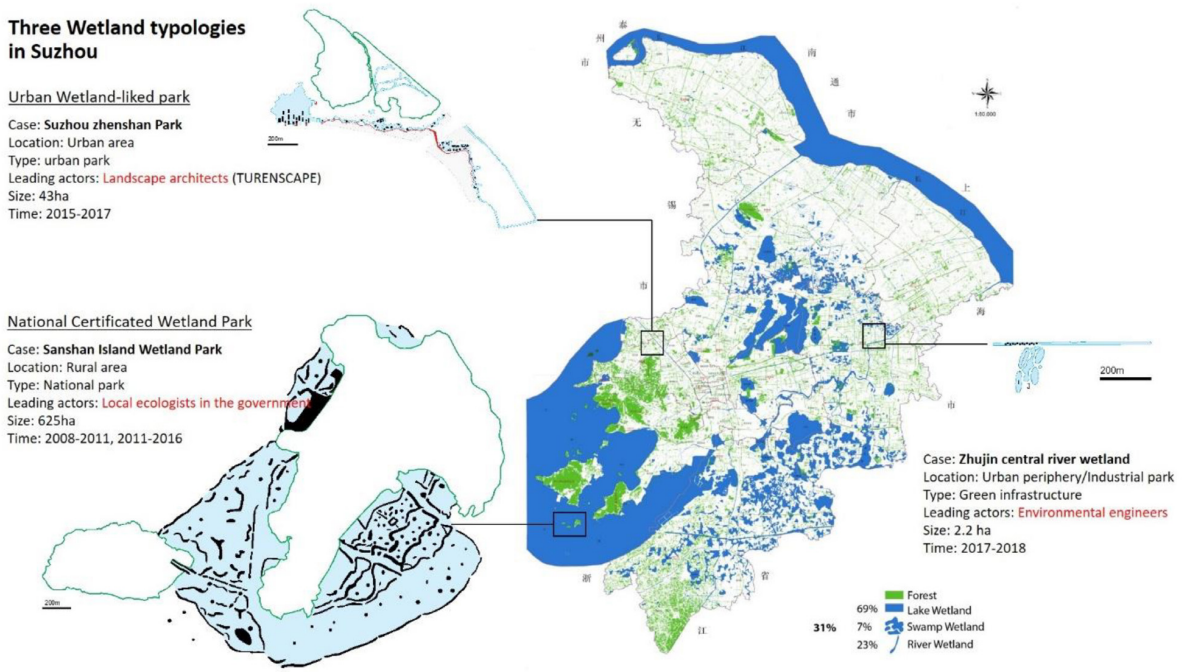

FIGURE 2 | Location map of three case studies in Suzhou, Source: made by author based on the Map of Suzhou Wetland resources (Suzhou Wetland Protection Management Station [SWPMS], 2019).

parks in Suzhou with transnational cooperation on biodiversity improvements. According to the current three spatial levels wetlands conservation regulations in China, most of the national wetland parks are more substantial in size and located in rural areas where potential biodiversity value is higher (**Figure 2**). The park is co-managed by the local government authorized park management office and Suzhou Wetland Protection Management Station (SWPMS). SWPMS is a unique semi-independent local institution under the supervision of the Suzhou Forest Bureau. It is the primary institution that provides the industry guidance to wetland park construction in China now. The second case, Suzhou Zhenshan Park, is an urban wetland landscape park constructed in association with the urban regeneration and boom of park building. Different from national wetland

parks, these landscape parks are incorporated in a different system, which is supervised by a local planning bureau. Suzhou Zhenshan Park is located in urban areas that prioritize wetland aesthetics and recreational value for surrounding residents. Landscape designers thus became the main actors in leveraging the wetland design with developers and governments. The third case, Zhujin Central River wetland, is an engineering-constructed wetland that was specially designed for collecting and purifying wastewater before it goes back to the river. It is the smallest size of wetland with highly functional plants and bio-engineering techniques. The environmental engineering company is the leading actor and claims that the constructed wetland can be an eco-tech solution to water degradation in China (Stokman and Jorg, 2013).

Although the three cases are distinguished in terms of location, size, and leading actors, they are all key projects that contribute to wetland decentralization governance practices in Suzhou. They share similar local aspirations to create a world city with a good environment through the innovation of wetland constructions.

The research mainly adopts qualitative methodology, which includes content review, site visits, and semi-structured interviews (see **Table 1** for the 20 interviewees and their roles). Interviews were conducted with the main stakeholders, such as experts (i.e., ecologists, landscape architects, engineers, and other specialists) and local government officials. Interviewees were selected based on the snowball sampling method recommended by initial informants in the local government. Those interviewed were asked about their experiences and opinions on developing these wetland projects. The author has built long term relationships with these critical stakeholders and visited each of the three sites three times during the last two years. Data collected from documents, observations, and interviews are analyzed based on the interpretative approach, which acknowledges the contextual and constructiveness of people's knowledge. Based on that, the following section synthesizes the unique wetland governance in Suzhou into three modalities with distinct forms, approaches, and purposes. The underlying aspirations of individuals to the wetland and ecology are analyzed.

WETLAND GOVERNANCE IN SUZHOU: MATERIALIZATIONS, APPROACHES, AND ASPIRATIONS

New Guardians of Biodiversity: The Rise of Local Ecologists

To investigate how the wetland conservations have been realized on the ground, I first approached Suzhou government officials who are constructing the National Certificated Wetland Park as the direct materialization of the top-down policies. These local officials are associated with the SWPMS, which was established in 2009. SWPMS stands out as an innovative institution among other cities in TLB and is focused explicitly on urgent wetland conservation. Officials in SWPMS are recruited mainly from the field of ecology. SWPMS has its own research labs that

TABLE 1 | Summary of data collection (Made by author).

Cases	Interviewees	Roles	Point of views
Sanshan Island National Wetland Park	Local government officials (5)	Ecologists from (SWPMS) who are managing wetlands in Suzhou	• Wetland is designed for increasing local biodiversity, especially for the co-existence of migratory birds and humans.
		Managing fishing and transportation in Tai Lake	• Confirmed the re-naturalization of banks in Tai Lake in recent years.
	Residents (2)	Nearby residents	• Witness the re-planting of reeds in Tai lake waterfront.
	NGOs (2)	Participated in the Nature Wetland School program in Suzhou	• Nature education is a curial step to establish the awareness of environmental protection in society.
Suzhou Zhenshan Park	Landscape designers (3)	Employees of the landscape company (TURENSCAPE). Two of them are the major designers of the case	• Wetlands consist of a series of ponds that can help the site to contain rainwaters and mitigate floods. • Use large scale master plan as an initial step to support the feasibility of the wetland park. • ·Wetlands with the beauty of weeds are cultural landscapes that connect humans and nature in cities.
	Local government construction and development company directors (2)	Design director and construction director	• Wetland parks as a public landscape work should also keep economic and low costs.
	Urban planners (2)	Local planners who are aware of TURENSCAPE's wetland approach	• Agree with wetlands as a cultural identity of water town (Suzhou).
Zhujin Central River Wetland	Environmental engineers (3)	Responsible for the case from planning to design, construction and maintenance	• Difficulty to acquire lands for constructed wetlands. • ·The importance of residents to understand wetlands in order to reach a balanced local ecosystem.
	Local government officials (1)	Ecologist from (SWPMS)	• Constructed wetlands are an emerging type in China. Its impacts still need long time observation.

SWPMS, Suzhou Wetland Protection Management Station.

monitor the wetland ecosystem in Tai Lake. They are pioneers in establishing local wetland laws, regulations, and plans for Suzhou, which have since set the standard for other cities in China. The conservation rate of wetlands in Suzhou has risen from 8% in 2010 to 58.5% in 2018 (Suzhou Wetland Protection Management Station [SWPMS], 2019).

As noted by those currently working in the SWPMS, National wetland park governance in Suzhou shows both input from transnational corporations and the gradual strengthening of local ecologists' roles. As is the case in many of China's cities, the idea of establishing national wetland parks in Suzhou was affected by international agendas on biodiversity conservation, for example, in terms of birdlife and other species. The State Forestry Administration often organized study trips for high-level government managers to other well-acknowledged wetlands since the 1980s.

'We have learned advanced wetlands management system in those wetland parks. Most of them are operated by international Environmental non-governmental organization (ENGOs) such as World Wide Fund for Nature (WWF).'

'After we established the SWPMS, we are keen to visit Mai Po wetland reserve in Hong Kong because of its high reputation in wetland conservation and management. I paid a self-trip to Mai Po with a professional team of bird watching around 2011. It was my first time to see the endangered Black-faced Spoonbills. I was impressed by how the wetland has been well managed by a professional team and can reach coexist between birds and humans. This experience strengthened my confidence in the protection of Suzhou wetlands' from an interview with a local government official in SWPMS.

Meanwhile, international ENGOs are also actively transferring environmental conservation ideas into China by setting up their offices since the 1980s. In the case of WWF, it is the first international NGO invited by the Chinese government to work on nature conservation. In 2007, WWF set up a Shanghai Office. The initial cooperation between WWF and local governments in TLB includes Water source protection of the Huangpu River and east Tai Lake, Yangtze protected area network in Chongming national nature reserve, and Low carbon city initiative. The international reputation and local practices of WWF attract the attention of SWPMS.

'*SWPMS has 8 years of cooperation with WWF. However, gradually I feel their progress is often limited by their inability of publicly raise funds in China. Therefore, the most effective cooperation for wetland conservation in China is often learning concepts from international ENGOs while implemented by local government bodies.*' From an interview with an official in SWPMS.

The best case is the Sanshan Island National Wetland Park, which bears witness to 8 years of progressive cooperation between the Suzhou government (SWPMS) and WWF. The focus of initial cooperation was improving the sustainability of wetlands as well as the livelihoods of those living in surrounding villages, which was marked by the first agreement of 'wetland 1 + 1' signed by the local government, private enterprises, and WWF in 2012. The SWPMS hopes WWF becomes the bridge between wetland villages and enterprises to form water stewardship, which in turn will broaden local funding channels for wetland conservation. One enterprise will be paired with one wetland village in Suzhou to invest in wetland technologies, promoting organic agriculture and ecological tourism. However, WWF seems more to be adhering to the agreement format rather than actually investing human resources and capital in the project.

The wetland 1 + 1 of Sanshan Island ended with no clear progress. The experience, however, has led to a critical shift in later transnational cooperation toward the construction of 'Wetland Nature School' in Sanshan Island. Wetland Natural School is a practical alternative in wetland governance that is reshaping human and natural relationships. Under the existing wetland park plan, for example, Sanshan Island National Wetland Park has been divided into six functional zones: wetland conservation areas, a restoration and reconstruction area, an educational exhibition area, a rational utilization area, a management service area and a community co-built area. The national wetland park has now been mobilized as a spatial milieu to convey the ecological governmentality not only to the government and private sector but also to the broader public through wetland education. Volunteering, teaching, and public participation programs have been developed in the park with the help of WWF Shanghai and local efforts. Based on the long term development of wetland parks in Suzhou, SWPMS has also invented new assessment criteria for certified national wetland parks in Suzhou. They synergized complex technical data into three indicators: water transparency, bird biodiversity, and education programs. These criteria have subsequently been adapted by WWF and spread to wetland management in Guangzhou and other cities in China. These growing aspirations of reshaping an alternative future for the city through wetland construction are also reflected in the views from Secretary Wu on the Sanshan Island. According to the online news, Secretary Wu built the Sanshan island wetland park from scratch long before the national system certified it. Since 2008, he has initiated the existing layered wetland design approach in the Sanshan Wetland Park (**Figure 3**). It was a tough decision at that time as he faced issues such as the degraded water quality caused by early tourism development, needs for sustaining tourism, and limited village funding. Many people were skeptical about his approach at that time, but secretary Wu persisted in his endeavor. He stated in the news that if the island could not attain clear water in Tai Lake, it would gradually lose its charm and attraction. A pleasant environment, meanwhile, would have a positive effect on tourist development (Wang and Song, 2012).

Those claims were clearly based on his experience and observations as a local resident. As a self-educated local ecologist, he thinks that building layered dikes in the wetland can be useful in mitigating algae bloom on the lake, preventing soil erosion on banks, and, more importantly, forming a natural ecosystem for birds, plants and fish. The success of this typology raised the attention of local government officials, such as the director of SWPMS. Since then, it has been developed as a 'multi-layered cofferdam' approach that has been adapted in many other national wetland parks in Suzhou (Suzhou Daily, 2019).

Although local officials in SWPMS and the village secretary may seem to be the end recipients of globalizing wetland

FIGURE 3 | Layered artificial islands in Shanshan National Wetland Park [Source: provided by Suzhou Wetland Protection Management Station (SWPMS)].

governance, they are all committed to the local wetland construction. They not only serve as traditional local officials facilitating orders from above, but more as initiators answerable to the public who take brave actions based on local ecological values and ethics. Their roles in local wetland constructions are reflexive under the seemingly international agendas and state regulations. This shows the collective vision in which wetlands can sustain biodiversity and build a better future for both humans and nature.

Recall the Balance of Human and Nature Relationships: Cultural Landscape by Landscape Architects

Except for the state wetland conservation governed by local ecologists, landscape architects also adhere to the notion of wetlands through advocating urban wetland landscape parks for local governments. With China's increasing urbanization in the 1990s, landscape architecture became an essential branch of the booming building industry. From their origins as commercial designers for the real estate landscape, many landscape firms can now take on significant commissions in local governments' regeneration projects. Through open bid, national or global landscape architects can provide professional services for the design of local public parks. Wetlands have become a popular design concept for urban parks as the government's priority has shifted from the previous focus on pure aesthetics to ecological security under the central attention to environmental conservation. It needs to be noted that the popularity of wetlands cannot be delinked from the growing notion of environmental commodification, in which a healthy urban environment can increase surrounding land values, attracting investment and further branding cities in a global sphere (Castree, 2003, 2008).

An essential urban wetland landscape park in Suzhou discussed here is Zhenshan Park, which has just been nominated for the world-wide design award (Azure, 2020). The predecessor of the park was a redundant landfill site. It was always a headache for the Tong'an town government as it is located at the entrance of the district. In 2014, the town government decided to regenerate this area for future commercial and recreational use but they don't have a clear vision at that time. The town government secretary approached the TURENSCAPE because of the reputation of its founder, Kongjian Yu, for ecological designs such as sponge cities, wetland parks, and green infrastructures. Thus, TURENSCAP, the leading domestic landscape architecture firm in China, was hired to design a landscape park in this area.

'The first step we usually do is to argue the park location with local governments. While the government might want to fill in the land with more buildings, we would suggest keeping the low-lying areas in the original site and transfer into rain collecting ponds. Thus, the places can be resilient for future floods.' Said by a former landscape designer at TURENSCAPE.

Similar to this process, the design team in Zhenshan Park also negotiated the possibility of ponds with the town government by making a concept plan first for the whole site. The concept plan included the arrangement of surrounding buildings, water systems and showed how the building directions, entrances, and functions fitted with the visitor circulation in the park. Then, the main issue was around the size of ponds. In the initial plan, TURENSCAPE proposed to dig more areas as ponds to connect the water system. However, the director from the Tongan town government construction and development company suggested limiting the new earth excavation in order to keep the balance between excavation and fill, which is a popular strategy to control the cost of landscape work. After reaching the agreement, the concept design was constructed quickly. One year later, Zhenshan Park, a wetland landscape park with naturalized plants and stepping water flow, has been built to collect and purify rainwater. More importantly, the park provides a free recreational function for surrounding residents (**Figure 4**).

Compared with previous national wetland parks, urban wetland landscape parks built by landscape architects are less about biodiversity indicators and more about the aspirations

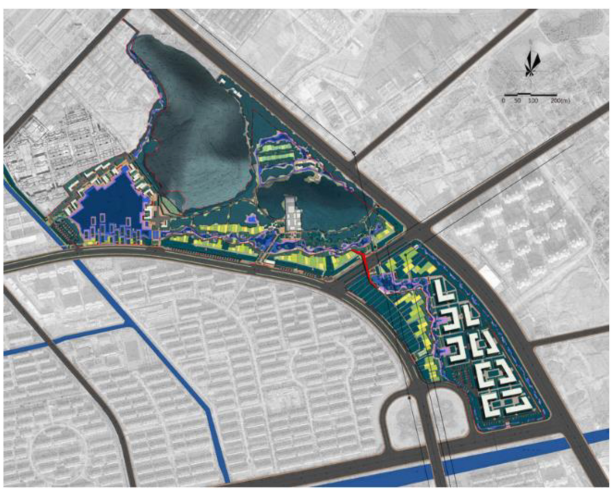

FIGURE 4 | Early master plan of Zhenshan Park made by Turenscape (2018).

of cultural landscape values. This can be traced to a series of ethical claims made by the founder, Kongjian Yu, about Chinese landscape development. Yu thinks the priority of landscape design lies in respect for nature, humans, and local place spirits (Turenscape, 2003; Saunders, 2013). A typical identity that has been acknowledged in TURENSCAPE projects is the nostalgia for 'Beauty of Weeds.' In Zhenshan Wetland Park, productive plants have also been reintroduced, such as paddy rice and sunflowers. The imitation of nature approach has also received criticisms from ecologists who are skeptical about the purification efficiency of these plants.

Meanwhile, a visitor circulation plan guided by striking red-belt seats and public spaces has been integrated into the Zhenshan Park, as well as many other parks designed by TURENSCAPE. While critics, like ecologists in SWPMS, think the iconic design is irrelevant to wetlands ecology and merely serves as a company brand, the founder, Kongjian Yu, thinks the iconic design also serves as clear guidance for humans to explore and form a closer bond with nature (**Figure 5**). Yu thinks that the only path to reach the ideal city is through combining nature and human culture (Yang, 2014). Yu is enthusiastic about restoring naturalized and ordinary landscapes, while he despises the decorative landscapes in traditional Chinese gardening.

While not all landscape architects agree with Yu's radical approach to Chinese landscape design, his enthusiasm for generating public attention to water landscapes and human relations is shared by other local landscape architects and planners. In interviews, they have also stated that people should be able to get close to nature, especially to water in urban parks, which will ultimately strengthen the identity of Suzhou as a Watertown.

The case of Zhenshan Park suggests that landscape architects are on the rise as important actors in transferring ecological notions such as wetlands to local governments under contemporary urban development in China. More importantly, their roles have shifted from being simply designers to being facilitators in local government decision making. The new role is tied to their historical and cultural experiences, which underscores the fundamental moral value of wetlands and their potential as a critical cultural element in reshaping Suzhou's future.

FIGURE 5 | Zhenshan Park after built (Photo taken by author).

Wastewater Purification for the River: Balancing Local Ecosystem by Environmental Engineers

The movement toward a more marketized neoliberal governance in China's environmental regime opens the door for multiple stakeholders from different disciplines to become involved in local wetland construction. While local ecologists and landscape architects are the two main actors in wetland making in China, environmental engineers are also rising as emergent actors in building constructed wetlands, especially for wastewater purification. The growing importance of environmental engineers cannot be delinked from local political missions created by the indicator gap between the existing purification ability of wastewater treatment plants (WWTPs) and the acceptable quality of effluent discharge according to guidelines of the ecological civilization requirement in China. According to the latest Water Pollution Control and Action Plan in 2015, in the context of ecological civilization, China is aiming to improve the water quality in all urban rivers in order to reach Grade V level (State Council, 2015). Since then, the indicator has been increased to Grade IV before all the sewage can be released back to rivers, according to the National Towns and Cities Sewage Treatment and Recycling Facilities Construction Plan released in 13th 5-Year Plan (National Development Reform Commission [NDRC], 2016). However, the current highest level of sewage water after processing in WWTPs is still lower than Grade V (COD 50 mg/L; State Environmental Protection Administration [SEPA], 2002).

The indicator gap creates a niche market for constructed wetlands in China, which have proved efficient in purifying the polluted water from lower Grade V to Grade IV (Bai et al., 1999). Kunshan Zhujin Central River Wetland in Suzhou is a typically constructed wetland that amplifies the bio-purification function of the ecology (**Figure 6**). The original Zhujin River was polluted by discharges from surrounding factories and households for a long time. The town government has received several complaints from residents regarding the black and evil-smelling bodies of water. Several attempts for restoring rivers have been undertaken, such as traditional micro-aeration and planting small scale aquatic plants in the rivers. In 2017, the town government started a new round of open tendering, which aims to look for a new approach to improve the river water. Suzhou Dehua Ecotech Company won the tendering with the support of their strong local experiences in engineering wetlands. The company has more than 20 constructed wetland projects in the TLB with various scales and contexts. Therefore, the company is responsible for wetland construction from initial design to maintenance.

During conversations with engineers working on this project, it was revealed that there are attempts to treat the constructed wetland as a small part of the whole ecological engineering program for the river water purification. The constructed wetland

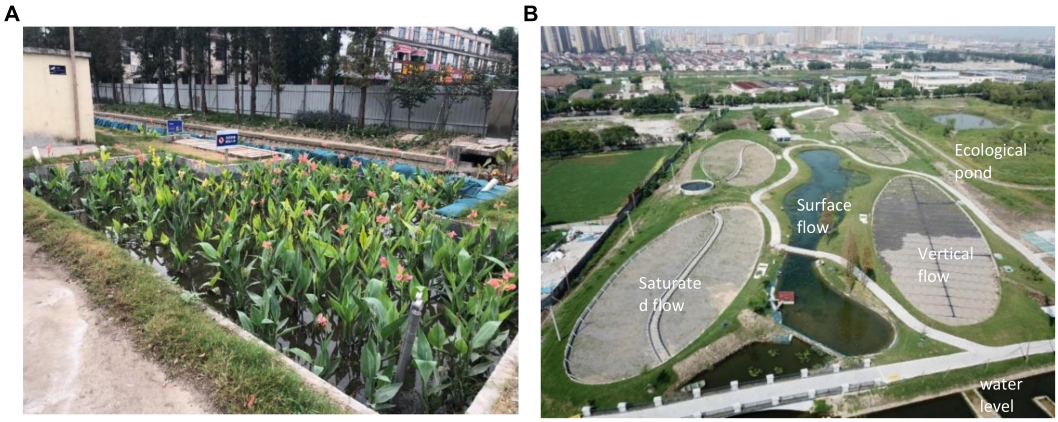

FIGURE 6 | (A) Functional plants in the constructed wetland system (Source: provided by Suzhou Dehua Ecotech company). **(B)** Aerial photo of the constructed wetland after built in 2018 (Source: provided by Suzhou Dehua Ecotech company).

is highly engineered with a series of ponds: water level regulating pool – vertical flow wetland – ecological pond – surface flow wetland – and saturated flow wetland. The different ponds will be planted with different functional plants, such as *Canna indica* and *Arundo donax* 'Versicolor.' The sewage water after leaving the WWTPs will go through these ponds, which are powered by the solar power station, and monitored through the smart remote-control system, in order to achieve the Grade IV level for wastewater before returning into the river.

'Though it is a small-scale wetland whose technology is quite mature abroad, it is never an easy job in the cities of China.' Comment from an environmental engineer in charge of the Kunshan Zhujin Central River Artificial Wetland Project.

The difficulties are concentrated mainly in the negotiations with local government and residents in terms of both acquiring land and wetland management. First, unlike urban wetland landscape parks that have a clear land-use type, small constructed wetlands usually do not have a specified category in the land use planning of China. Most of the constructions built by the company are small areas of left-over land near the river, which have no foreseeable value for local governments. The local government's low expectation of the land value and the remote locations (rural or urban periphery) enhance the cost of wetland construction.

'Local governments think they are neither suitable for building houses or factories nor incentive to do greenery.' Comment by the Environmental Engineer.

Second, under the rising awareness of participation in China, engineers are becoming community coordinators who spontaneously work with local government to negotiate with residents during wetlands construction. Currently, most people in China still treat wetlands as landscaping without knowing the complex ecological system behind them. The low perception among residents has also caused unexpected risks for constructed wetlands. For instance, when the surrounding rivers are flooded, residents tend to discharge floodwater into the constructed wetland, which brings uncontrolled bacterial levels and water quantity to the wetland system. Therefore, as reported by the interviewees, they spend much time on communication with individual households who might be affected by the wetland projects. From a practical point of view, only when no one is objecting to building wetlands on the site, can the government then sign the wetland project contract with the company. On the other side, the engineer also links these endeavors with the ethical perspective rooted in their company's belief. This system illustrates that the engineering company treats humans as a vital component in sustaining a healthy local ecosystem.

'Wetland is a living organism in which the best performance can only be achieved when it is integrated with the local ecosystem circle. Humans are also vital energy flows in the local ecosystem.'

DISCUSSION

Given China's fast urbanization and eco-desires under the latest discourse on ecological civilization, experts and non-experts should understand the notion of ecology in terms of mainstream wetland projects. This paper reveals how the TLB has been transformed from a natural wetland to an agglomeration of wetlands under neoliberal capital rationalities. Focusing on the contemporary wetland construction in Suzhou, the analysis of localities involved in three wetland projects (Sanshan Island National Wetland Park, Suzhou Zhenshan Park, and Zhujin Central River Wetland) reflects three distinct modes of wetland construction in terms of materialization, approaches, and aspirations. Collectively, they also illustrate the local dynamics of wetland governance as a form of worlding city practices. By comparing the findings from the three cases, broad lessons can be articulated toward a novel understanding of wetlands in China.

The first lesson is that wetland constructions are mobilized by the individual's ethical claims around ecology, which are shaped by historical and cultural contingencies. Take the three leading actors in the cases as an example. Local ecologists divided natural wetland parks into different functional areas with disciplined behaviors, either no admittance to the public or participated in ecotourism. This zoning approach fits the

category of 'disciplinary environmentality' described by Agrawal (2005). This illustrates that ecologists are embedded in and are promoting the ethical norms, diffused by international agendas, in which biology-rich wetlands can build a better future for human and non-human species. Landscape architects, on the other hand, argue that wetland construction through rewilding landscapes and public space design is a way of reclaiming humans' essential interconnection with nature, which can be seen as a deep need in human beings (Fletcher, 2009). Finally, environmental engineers not only use their technical ability to oversee the wetlands' capacity to purify wastewater but are also actively involved in the conversation with local inhabitants to help them understand the notion of wetlands. They hope by increasing the people's understand of wetlands, a healthy local ecosystem can be formed, which will increase the efficiency of constructed wetlands to clean the water for rivers in return.

Second, the diverse ecological ethics have led to a convergence in reflexive roles taken by individuals, which in turn has formed the ecological governmentality defined in this article. The notion of ecology has been understood to be muli-faceted as a self-governance for building and restoring wetlands in the current environmental governance regime. This transformation also resonates with the early concept of 'Worlding Practices' and 'global-local nexus,' both of which address globalization as a multifaceted process constituted by different localities in the making. Although wetland conservation is a global consensus not confined to China, local actors have their own aspirations in achieving it. Local ecologists with updated knowledge of ecology and space attachment are prominent initiators in adjusting the environmental governance at stake. Landscape designers, in the context of demanding urban environmental improvements, can be good facilitators in getting ecological notions incorporated in the government officials' decision making. Environmental engineers, under the pressure of public participation, can be good community coordinators who can mediate disputes between wetland management and residents concerned about their livelihoods.

The third lesson can be drawn from the consistent resistances that have happened during wetland maintenance. In the case of Sanshan Island National Wetland Park, it is managed by the local property management company joined by the tourism company, the district government and the village joint committee. The company hires existing local villagers to manage the daily activities in wetland parks, such as maintaining the landscape and collecting fees for recreational activities. The co-management mechanism is a unique participation mode in China and raises contestation about the short-term economic value and long-term ecological value. During my fieldwork in Sanshan Island National Wetland Park, it was found that villagers sometimes played music extremely loudly at the pier used by boat tours in order to attract tourists to take the boat and consume refreshments in the nearby tea house. The overly loud music might terrify the protected birds in that area, which in turn might decrease the ecological value of the wetland park. Instances such as this are also common in other wetland parks and nature reserves where the residents tend to chase the economic profit brought by the recreational business. This of course conflicts with the primary intention of ecological conservation for non-human species. Alongside the previously mentioned flooding resistance in Zhujin Central River Wetlands, this paper reveals the existing limitation of environmental education in China, which mainly focuses on the middle-class population living in urban areas rather than rural inhabitants, especially those people living close to wetlands. It is essential, however, that future wetland experts consider a broad range of users in relation to wetlands, especially local, low-income people, many of whom are not educated.

CONCLUSION

Wetlands are critical resources for coastal cities that suffer from climate change and urban development. Its adaptation demands locally based governance, which not only relies on science rationales but also human dynamics. Through analyzing three wetland construction cases in Suzhou, this paper sheds light on the fact that the current mainstreaming wetland constructions in Suzhou cannot be interpreted simply as the impulse of environmental commodification under neoliberal capitalization, but is instead a contested materialization in which different social actors seek to break away from established norms and reshape urban futures on their own. This underscores the power of moral ecology in wetland governance and highlights the reflexive responsibility that each local actor has, both as a city culture activist and a participant in the future decentralization of wetland governance.

Developed further in the discourse of governmentality, this article elaborates the fact that environmental degradation, along with economic boost, has driven local experts to adopt particular ethical positions in ecology, which they believe are necessary for making Suzhou a better city. These transformed positions as "ecological governmentality" are shaped by individual historical circumstances and disciplinary training. Situated in the previous critical literature of expertise and politics, this article shows another possibility where local experts, under the worlding city mentality, collectively endeavors to contribute to wetland conservation and construction in China. However, it must be pointed out that the existing interactions among three leading experts (ecologists, landscape designers, and environmental engineers) in local wetland governance are constrained by the split institutional structures. Three types of wetlands designed by them belong to different land uses. Thus, they are supervised by different governmental departments such as the forest bureau, planning bureau, and water affairs bureau. Some of them are often skeptical about each other's work due to disciplinary differences. Therefore, the fusion of these disciplinary gaps both in wetland science and wetland governance is needed.

Further research in wetland governance in China can develop further on the use of these ethical claims on ecology. As literature has pointed out, some experts are now being politicized. They are using moral claims as a depolitical strategy to achieve their goals in environmental politics. Therefore, more research is needed to examine to what extent local ecologists, landscape

designers, and other environmental experts in Suzhou are using moral ecology to avoid project disputes and enhanc their powers in the wetland industry. As said, since the decision making in wetland construction has convergence in ecological considerations, whether it can be the leverage point for different actors to work with each other remains to be seen. Moreover, broad local stakeholders can be interviewed in the future, which includes more local residents and users of wetlands. Questions can be asked such as: Are they also using ethical claims as self-government to promote wetlands? How are the values and aspirations of residents on wetlands different from those of local experts? Lastly, spatial scales of investigation can be expanded. Three wetland construction modalities proposed in this article based on the situation in Suzhou can be compared with other cities in TLB, in order to have a comprehensive understanding of the wetland governance in this region.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material. Further inquiries can be directed to the corresponding author.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Human Research Ethics Committee, The University of Hong Kong. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

The corresponding author prepared the manuscript and did all the field works associated with the study.

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Coastal Risk Cultures: Local and Regional Formation of Knowledge and Action

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This paper deals with how culture is expressed through the interplay of socially, politically, and economically driven processes and practices in place-based biophysical contexts as well as the role played by narrative expressions in the formation of coastal risk management, knowledge and action. It draws upon ethnographic, comparative, and historical approaches to understand how culture frames what we know and how we respond differently to risks. The research is based on the theoretical position that interpretation of risks and responses of social groups are shaped by frames of cultural knowledge and values, and investigates the influence resident's values have in shaping the resilience of their community in two coastal regions in Germany and Italy. Information was derived from desk research, semi-structured, narrative interviews, and observation. Specifically, the author was interested in how residents' views and narratives affected their risk behavior, shaped their needs and which role path dependencies and societal contexts played in the formation of risk knowledge, risk management and action. The author found that values, knowledge and identity highly matter in building community resilience. Moreover, the cases illustrate how past and present societal trajectories shape local and regional responses to climate change and why this concerns political decision makers at all levels, who are aiming to mainstream mitigation and adaptation strategies confronting climate change effects and in turn shaping resilience at local and regional levels.

Keywords: culture, values, risk, knowledge, action, resilience (enviromnental), coasts, Europe

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INTRODUCTION

Recent and historic high-impact events have led to significant flood risks in many coastal areas in Europe and across the globe. Specifically, between 1998 and 2018, Europe suffered from over 229 major damaging floods. These floods have caused more than 1600 deaths, the displacement of about half a million people and at least €52 billion in insured economic losses (EEA, 2019). Moreover, of the thirty largest cities in the world, 20 are in coastal areas and therefore endangered by global climate change and associated sea level rise. Inundation, erosion and other risks are expected to increase due to our changing climate as well as the further development of coastal regions, and will thus require appropriate prevention, mitigation, and preparedness measures (World Economic Forum [WEF], 2019). Consequently, the management and communication of risks has become a major question of public policy (Alexander, 2000).

Various scientific disciplines are closely linked by their ways of investigation perspectives to the life-worlds of societal groups and individuals. For instance, anthropologists, who consider culture their defining concept, have provided manifold empirical evidence that societal groups are bound by specific shared values that are expressed semantically and materially in place-based contexts (Geertz, 1973; Dove and Carpenter, 2008; Kruper, 2010). Psychologists, sociologists, geographers, environmental historians, political scientists and others have contributed to illustrating the close relationship between risk identification, responses and culture (Brien and Wolf, 2010; Fresque-Baxter and Armitage, 2012; Adger et al., 2013; Clarke et al., 2018; Lemée et al., 2019), leading to the conclusion that society's risk management is to a large extent mediated through culture (Grothmann and Patt, 2005; Kings and Ilbery, 2010; Hards, 2012; Martinez et al., 2018). The focus of this paper is therefore concerned with the cultures of two coastal communities and the contexts in which the values, knowledge and actions of its residents are embedded and modified, and through which they influence the resilience of their communities toward coastal risk management. Chabay et al. (2019) argued that narratives "provide insights into how a desirable future is envisioned and expressed" while "the motivations of individuals and groups for acting in support of, or opposition to, the expressions of vision are strongly influenced and may be inferred from narrative expressions of identity, culture and contexts." The two chosen case study sites (the islet of Ummanz in Germany and the sea-side resort Porto Garibaldi in Italy) are examples further illustrating the deeply layered connectedness which exists between culture and risk management, knowledge and action.

MATERIALS AND METHODS

This article starts by presenting the two case study sites and methods used in the study. Then, results are discussed concerning the role of local risk cultures in relation to flood risk management and how the formation of knowledge and action relates to resilience and management in the case study sites presented. The discussion also includes recommendation and an outlook on the role of local cultural knowledge for policy making on climate change adaptation.

Description of Case Study Sites

Baltic Sea Coast, Germany

The Baltic Sea is considered the largest brackish sea worldwide, bordering Germany, Denmark, Sweden, Finland, Russia, Estonia, Latvia, Lithuania, and Poland. The water level of the Baltic Sea is subject to constant fluctuations, the highlights of which are storm floods. Low and/or high-pressure systems in the region are frequently able to generate strong winds, which can push water through the sound and belts into the Baltic Sea, raising the sea level in the entire basin. Sometimes hurricane strength can be reached (State Office for Environment and Nature Rostock Coastal Department [SOENRCD], 2009). The heaviest storm surge in the Baltic Sea recorded thus far by level measurements occurred on November 13, 1872, causing the sea level to rise to 3.3 m above average. In Germany, Denmark, and Sweden more than 271 people died, 15,160 lost their homes and 2.860 houses were destroyed (Hupfer, 2019). Even today, exhibits in local history museums and flood marks in communities along the Baltic coastline commemorate this event. Soon after the catastrophe, German newspapers reached out to the population of the newly founded German Empire, making an urgent call for the collection of emergency funds to support the victims' recovery. Moreover, the 1872 flood was both the occasion and starting point for the development of modern coastal protection in Germany. Interestingly, Germany's first chancellor, Bismarck, had his first public office as a dike warden in 1845 where he was "responsible for preventing the Elbe from flooding the countryside" (Feuchtwanger, 2014). Under Bismarck, the Prussian government from then on systemically developed coastal protection measures by planning dikes connected with upstream beach and dune areas. Even today, the design bases for coastal protection structures in Germany are still oriented toward the water levels reached during the 1872 flood, commonly referred to as a "one in a 1000 years flood" (State Office for Environment and Nature Rostock Coastal Department [SOENRCD], 2009). The event is still of scientific interest as the subject of simulation with the help of computer models (Bruss et al., 2009). There are indications that storm surges in the Baltic Sea will become more severe and frequent in the coming century (The BACC II Author Team, 2015).

Ummanz at the Baltic Sea Coast, Germany

Ummanz is an islet of about 20 square kilometers in size and located in the western part of Rügen, Germany's largest island. It has always been a sparsely populated and dispersed rural area, away from the tourist crowds. In the early 20th century, a 250-m-long bridge was built to connect Ummanz to the main island Rügen. In 1953, electricity reached Ummanz. It is situated in the former GDR, and about 240 residents live on the islet today. High unemployment rates and an aging population characterize the region.

The island lies only a few meters above sea level and is faced not only with the challenges of storm surges, but also has to cope with heightened groundwater levels due to the rise of the sea level and the absence of measures such as levees, dams or designed flood areas. A significant number of residents would be affected by floods (Martinez et al., 2014). It is obvious that Ummanz has always been exposed to natural hazards, and so the risk associated with living on the islet has always been high. Nevertheless, in the past, residents chose to live with these risks in return for agricultural gains on land artificially reclaimed by their ancestors while still feeling sheltered by a ring wall erected in the 19th century–already as a response to the extreme storm surge event of 1872.

Adriatic Sea Coast, Italy

Storm surges pose a serious threat to cities of the Adriatic coast, with Venice being hit hardest by floods. Along the Adriatic coastline, 100 kilometers are situated below sea level, exposed to the risk of flooding by sea surges and rivers. "Man-induced or natural subsidence has affected most of these areas, especially

near the Po Delta area, where an altitude of over 2.5 m was lost in some places during the past century" (Bondesanf et al., 1995).

Porto Garibaldi at the Adriatic Sea Coast, Italy

Porto Garibaldi is one of the oldest seaside resorts in northern Italy, an important fishing and tourist destination approximately 100 kilometers south of Venice. Originally a pure fishing village, it today comprises an almost 10 kilometers long stretch of coast, located in the Ferrara and Ravenna provinces, in the region of Emilia-Romagna. Because of its low houses, Porto Garibaldi still gives off the appearance of a fishing village, housing around 4,700 residents today. The port of the town is still home to many fishing boats, but also serves as a recreational port and the mouth of a waterway, which leads from the hinterland to the Adriatic Sea. Every year folklore festivals and events take place, including the celebration of the Madonna of the Sea in June with the traditional procession of decorated boats. Despite such iconic spectacles, the area is exposed to marine floods and erosion. In the past, groundwater and gas extractions have been carried out and wetlands destroyed. Since 1946, 79 major storm events have been recorded (Armaroli et al., 2014).

Frame for Investigating Coastal Risk Cultures in the Case Study Sites

Generally, resilience is understood as the ability of a system to cope with changes, perturbations or shocks and to return to it's original status, to adjust to the new circumstances and to reduce future risks and vulnerabilities. Perceptions of environmental risks play a critical role when determining the degree to which people are at risk. The significance of culture in understanding why people perceive and act to risk in particular ways is understood as risk culture. Since the beginning of people living together and interacting with the environment, they have constructed stories and with them narratives in verbal, figural or musical forms. Often they deal with events including risks which force actions of the characters involved to overcome those.

Based on the premise that risk assessments are objective analytical processes while risk experiences are subjective "social and cultural processes that shape interpretations of events" (Pidgeon et al., 2003), three interrelated value sets were found particularly relevant for the explanation and interpretation of the risk behavior of people in the examined case studies in Germany (the coastal island of Ummanz in the Baltic Sea) and in Italy (the Adriatic coastal town Porto Garibaldi): Nature and the sea; cultural identity and risk culture; and cultural identity and socio-economic values. These three value sets are important as they explain local interests and attitudes to the coast and sea aesthesia while determining community's identity, perception of risk and consequently the ability to find and implement acceptable solutions to increase adaptive capacity and in turn resilience.

Primarily oral history methods have been applied in this research to explore how socio-cultural, economic and political developments were able to influence the resilience in the two coastal case study areas. Oral history is defined as "a process of collecting, usually by means of tape-recorded interview, reminiscences, accounts, and interpretations of events from the recent past which are of significance." (Hoffmann, 1984 p. 68). In addition, participatory observation was carried out involving active looking, informal interviewing and writing field notes (DeWalt and DeWalt, 2002).

Further materials were viewed in archives and museums as objects and sources that survive in collections demonstrate appreciation of thoughts and activities of people of the past and are often engrained in the collective culture of a community acknowledged as material and immaterial heritage. For this study the author visited the archive of the community of Ummanz and the cultural history museum of the City of Stralsund situated nearly located to the islet of Ummanz (Germany) and the museum of traditions and cultural material "La Tratta" in Ferrara as well as the manufacture of marinades museum in Comacchio (Italy), both in the province of Emilia-Romagna where the case study site Porto Garibaldi is situated. Hence, the types of data used in this paper derived from interviews/participatory observation (such as affective, emotional and other forms of expressions, and knowledge) and archival materials (such as chronicles, letters, photographs, paintings, or others).

Data Collection and Data Analysis

The investigations mainly used semi-structured qualitative interviews and observation with the intention of seeking different types of information from a historical and a personal level from the residents in the cases. Interviewees were selected through a small pool of initial informants suggested by partners working in the case study sites who in turn nominated other participants through their social networks. The focus of the interviews was to understand perceptions around climate change in general and coastal risks in particular, the local resident's culture of coping with and adapting to these risks, and the prerequisites for implementing adequate risk reduction measures. Interviews were guided by a protocol of written questions grouped into three categories: (1) cultural values; (2) coastal risk perception; (3) risk management and action. The length of an individual interview could vary between 1 and 2 h. Questions encouraged detailed rather than short answers as well as the bringing up of topics which interviewees considered relevant to the conversation. Conversations took place in comfortable environments such as meeting rooms, private homes or at the beach so that interviewees could entirely focus on the conversation.

In total, 24 interviews were conducted. With the agreement of the interviewees, conversations were recorded and later transcribed. The transcription followed the recording and hence contains characteristics of the oral history method such as partial and unfinished sentences or repetitions. The transcriptions were analyzed using the qualitative data software MAXQDA in order to identify common and different themes and development lines amongst the interviewees according to the three interview categories: (1) cultural values; (2) coastal risk perception; (3) risk management and action. Expressive quotes are highlighted in italics with the purpose of exemplifying the sentiments expressed as explicitly as possible. For illustrative purposes, some quotes are exemplarily assigned to the three interrelated value sets (Nature and the sea; cultural identity and risk culture; cultural identity and socio-economic values) which are in detail explored

in the sections below for each of the case study sites (Ummanz and Porto Garibaldi). In aggregated form the essence of the quotes are presented in **Table 1** in the "Discussion" section. The archival research occurred after the interview process and was used to contextualize the coded interview data. Handwritten documents such as the chronicle of the community of Ummanz (**Figure 1**) were acknowledged and materials objects viewed which demonstrate the heritage of fishermen, farmers and residents in the two case study sites. Both data sets are crucial as the enable to analyze the activities explaining how the past shaped their motivation for the present.

Ummanz

Nature and the Sea

Known for its relatively "unspoiled" nature, Ummanz has recently become a popular tourist location (See **Figure 2**). In spring and autumn, huge numbers of cranes gather to rest in the shallow waters of the bays and lakes, providing a spectacle of nature for several weeks. The islet belongs to the area of the "National Park of the Vorpommersche Boddenlandschaft," where tens of thousands of birds gather during migration seasons. Residents and tourists alike admire the calm atmosphere on the island. Residents frequently mentioned that Ummanz was:

TABLE 1 | Comparison of Risks, cultural values, risk culture and adaptation measures in Ummanz and Porto Garibaldi.

No	INDICATOR	Ummanz	Porto Garibaldi
1	COUNTRY	Germany	Italy
2	GEOGRAPHICAL FEATURES, TYPE OF ENVIRONMENT, ENVIRONMENTAL RISKS	Few meters above SL, island, coast, shoreline, marsh, polder, rural	Few meters above SL, coast, unique delta ecosystem, forest, wetland, semi-urban and rural settlements
		High-impact meteorological events such as storm surges, inundation, erosion and drainage problem	High-impact meteorological events (sea and river side) such as storm surges, flash floods, landslides, erosion and salt intrusion
3	MAIN Economic SECTOR(S)	Agriculture, ecotourism, conservation, nature protection	Tourism, agriculture, fishery, automobile industry
4	VALUES AND BENEFITS: Cultural identity, cultural assets, recreation, nature appreciation	Cultural identity based on a strong sense of place including a sense of security via a coastal protection dike (historical ring-wall); rich cultural heritage including myths, legends and a local dialect; cultural assets such as famous church altar of cultural and historical importance; nature appreciation such as scenery, aesthetics, wildlife; nature conservation	Cultural identity based on attachment to food and wine production and a rich farming and fishing tradition, strong entrepreneurial thinking; intangible cultural heritage linked to legends and festivities; recreational services for residents and tourists; partially man-modified coastline and hinterland with extensive touristic buildings and maritime transport
5	CULTURAL ASPECT IN SOCIETY: Values people attribute to their places; the level of risks they associate with the environment in which they live and the beliefs they hold about control and to adapt to its effects, accumulated social memory related to hazards	SOCIETY: Potential risk levels are perceived as not very high, subjective risk awareness seems to be influenced by trade-offs e.g., agricultural gains from reclaimed land of ancestors and the erection of a ring-wall in the past;	SOCIETY: high risk perception of residents especially owners of establishments near the sea; direct experiences of severe natural hazards in the recent past;
	GOVERNANCE: administrative practices in coastal management and functioning public services	GOVERNANCE: Trustworthy welfare system ranging from social security to coastal protection and risk management (dike building in the past); coastal protection is a federal responsibility;	GOVERNANCE: high level of bureaucracy, significant gaps between planners' intentions and planning outcomes e.g., in coastal protection,
	ECONOMY: production practices, entrepreneurial capacity, ownership	ECONOMY: weak economy (agriculture, ecotourism), modest unemployment rates due to new sources of income through ecotourism	ECONOMY: tourism is the strongest sector followed by agriculture, food production and fishing, strong entrepreneurial capacity
6	RELATION BETWEEN SOCIETY, GOVERNANCE AND ECONOMY: e.g., (mis)trust, (lack of) cooperation, lack of knowledge	The assistance of the state is not welcomed; feeling of loss of agency (the islanders have less and less power to enhance their resilience) has grown and there is a sense of hopelessness; tension between coastal authorities and residents; islanders believe the state should rebuild the ring-wall and protect built environment as well as reclaimed farmland	Trust and cooperation exist within the community; residents believe more could be done by the authorities to communicate risk and to implement adaptive measures to increase resilience of the area
7	HOW DO CULTURAL ASPECTS IMPACT RESILIENCE? Awareness, openness, the ability to cope with changes	Memories and knowledge of land reclamation and appreciation of the successes of it have passed on from one generation to the next, shaping a sense of holding on to the current protective measure although it is in bad shape; competency and ability to cope with disaster and setbacks are greatly overestimated partly due to the lack of personal experiences with extreme events but also due to mistrust toward coastal authorities	Location's beauty, rich history and culture are a source of pride; residents have limited access to information on risk mitigation but high individual capacity to cope with risks due to a strong entrepreneurial tradition; high flexibility in acting upon known risks; strong network of beach businesses established for purposes such as construction of winter dunes

Table adapted from Urbanc and Martinez (2020).

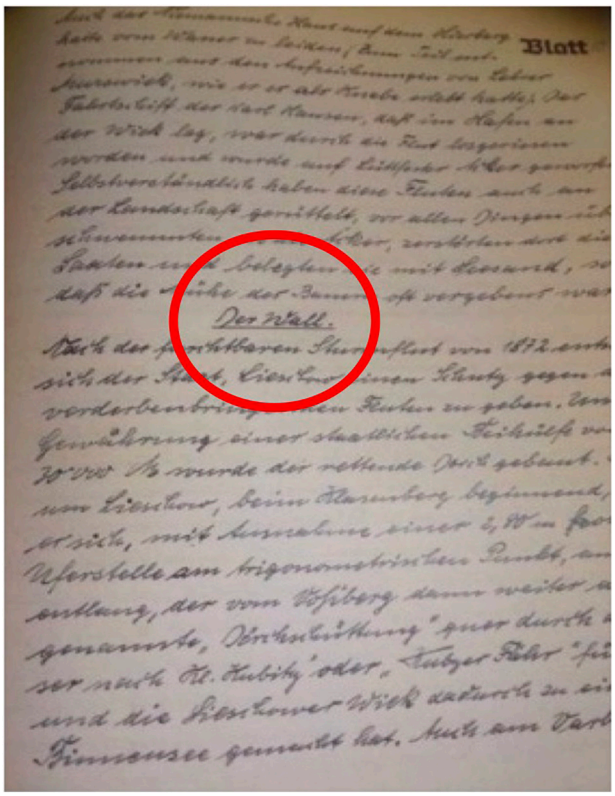

FIGURE 1 | Page from the village chronicle reporting about the construction of the ring dike ("Der Wall"–highlighted in red color). Source: Collection, Rita Hoff, annalist of Ummanz.

(1) "*A nice quiet corner which many like to visit… Guests keep saying that we should be careful that nobody destroys this for us… We have unspoiled nature, we have deer and wild boar… we have migratory birds in spring and autumn, we get up to 20,000 seabirds, this is quite a spectacle.*"

Cultural Identity and Risk Culture

From the late middle ages on, the sparsely populated island belonged to the nearby Holy Spirit Hospital in Stralsund on the main land. As a result, city dwellers exercised their rule over the island for centuries on behalf of the church foundation. However, they also gave gifts to the islanders: For instance, in the 18th century, Stralsund merchants, who had acquired a precious carved altar from the late Gothic period, originally made 1520 for the English church in Antwerp, donated the altar to the church of Ummanz' village Waase. The extraordinarily strong storm surge of 1872 with water levels above 3 m had threatened this and other valuable material goods and in the same year, the islanders already decided to erect a ring wall surrounding their settlements and scattered farmlands. Of course, this was only possible with the support of the Prussian state. The village chronicler reports:

(2) "After the devastating storm surge of 1872, the state decided to give protection against the destructive floods. A rescuing dike was built with a state subsidy of 30,000 mark" (Chronicle of Ummanz, author's translation, **Figure 3**).

It can be assumed that the awareness of their biophysical vulnerability has led the people of Ummanz to hold on to the conviction that the ring wall is a major protective adaptive measure to secure the islet, their property and their lives on it. This has enhanced the islet's resilience to natural hazards, understood as the capacity of the people of Ummanz to knowingly live and cope with this high-risk coastal environment. The following quote of a resident can be seen as a generally valid mind-set representative of the islanders:

(3) "*I am often asked are you not afraid for your house? But we have the wall and therefore nobody feels threatened by water here.*"

In the early 20th century, the ancestors of today's islanders made large parts of the diked land arable. The preservation of this land, its material, but above all, intangible value is important for many islanders today. Likewise, the material threat from flooding has always remained present on the island, since a large part of the claimed agricultural land is being kept dry by the communal operation of pump stations.

Cultural Identity and Socio-Economic Values

For centuries, fishing and later agriculture were the two main sources of income for the islanders. After the Second World War and the separation of Germany, Ummanz became part of the German Democratic Republic (GDR). Through land reforms, the islet received a different legal status and soon land owned by individual farmers became organized through cooperatives. Due to its peripheral location, the economic situation on the islet has always been challenging. With the exception of the years 1949–1989, in which Ummanz hosted a state-owned farm with more than 7,000 head of cattle and a fishery, agriculture is of lesser importance today and usually exists in combination with other utilization concepts such as ecotourism, while fishery has become almost extinct. About these years residents reflected by stating:

(4) "The state farm had 300 employees at that time, sometimes more, sometimes less in a full-time job but they were employed and I must say that we lived quite well then," while another resident pointed out that: (5) "The families here used to live from fishing… Nowadays fishermen are becoming fewer and fewer."

Indeed, fishery saw a sharp decline after the German reunification to the extent that only a few families continued to carry on their inherited craft. In combination with the promotion of tourist attractions such as crane watching, hiking, horse riding and other forms of ecotourism, agriculture continues to be a source of income. Today, cultural identity and socio-economic values of the islanders are built very much around farming traditions blended with tourist attractions like crane and bird watching, including breeding horses instead of cattle.

Resilience

In Germany, the right for protection only extends to built-up inhabited coastal areas. Recently, building permits near the coast are rarely granted. Not surprisingly, conflicts between the residents of Ummanz and the coastal protection authority arose

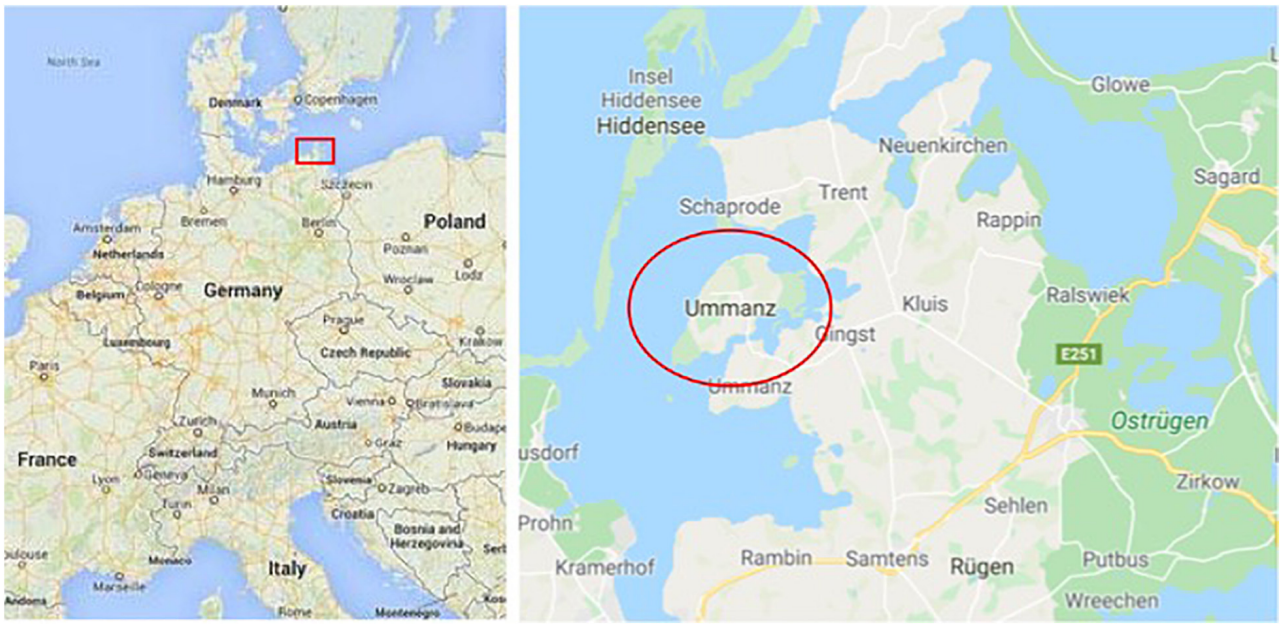

FIGURE 2 | Map of Ummanz. Source: Created by using map data © 2020 Google/INEGI.

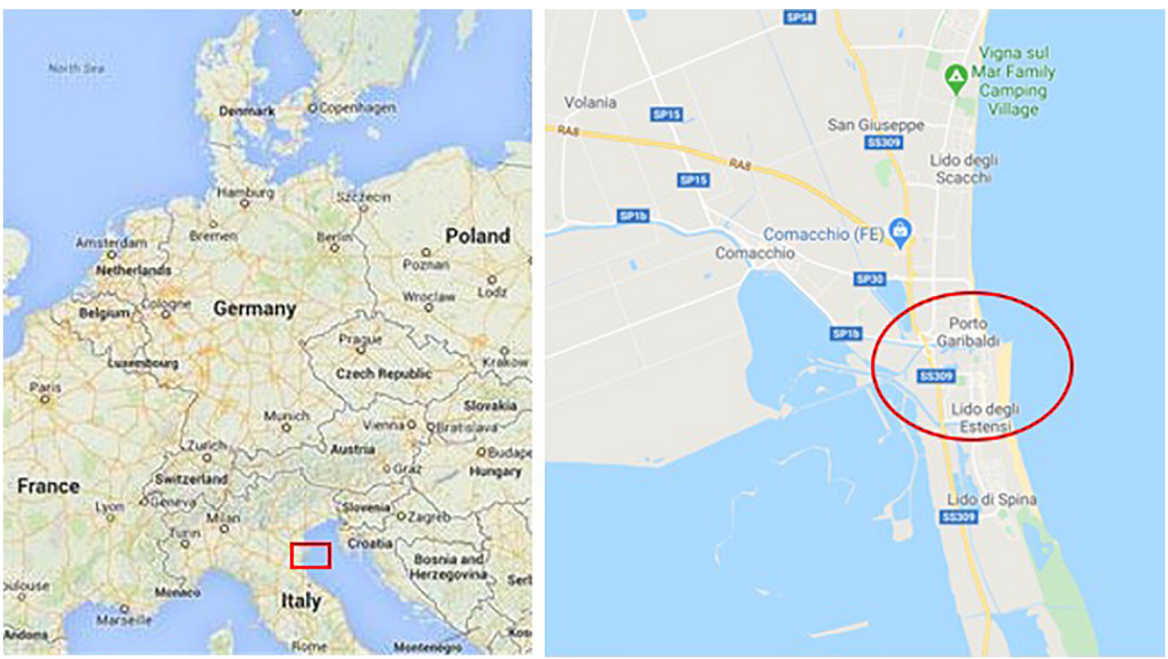

FIGURE 3 | Map of Porto Garibaldi. Source: Created by using map data © 2020 Google/INEGI.

with regard to safeguarding agricultural land on the islet. The community favors the preservation of the existing structure of the ring wall erected in 1874, which, by now, is in bad shape, while the authorities call for a so-called *crossbar solution*. This would mean building a new dike across agricultural land, eventually losing some of it to the sea but protecting the inhabited parts of the island from storm surges that may reach the historic heights of the 1872 flood. This coastal protection concept proposed by the state is seen by the islanders as a threat to the hard-won community identity and important intangible values, as many coastal areas have been actively reclaimed by the sea as a resident noted:

(6) "In 1850 the embankment of the island of Ummanz was started because the farmers suffered from the changing water levels, the big storm tide in 1872 tore everything away but the construction continued and it ended in the 1880's and the ring dike around the island of Ummanz was closed and now within the framework of the renaturation and creation of compensation areas the dikes that had only been used for agricultural purposes should be removed and a new dike should be built partly over the island where there are only dwellings."

Skepticism toward state-led planning measures seems to be high in Ummanz, which could be due to experiencing the transition to a new political and economic system after the German reunification, which led, among others, to the decline of formerly prosperous economies such as fishing and cattle breeding (Martinez et al., 2014). To date no further coastal risk measures have been implemented in Ummanz. Locals seem to prefer the *status quo* of being highly vulnerable to storm surges (since the current ring-wall is in bad shape) to a perceived loss of their cultural identity and economic sources when accepting a crossbar solution. This unsolvable conflict in Ummanz is closely linked to economic factors since the restoration of the ring wall option favored by the community would cost nearly twice as much as the crossbar option. As shown by the review of the history of the construction of the ring walls presented above, the stage for this conflict had already been set in the 19th century.

Porto Garibaldi

Nature and the Sea

Being the largest natural reserve in the region and a UNESCO World Heritage site, the area and its hinterland are characterized by the presence of wide lagoons, wetlands and canals. Most of the territory is extremely low-lying, with elevations at the coast ranging between 0 and 2 m above, and the hinterland being below mean sea level. The area has a high historical value: Etruscans and Romans established the first settlements. Because of the presence of many canals, the area is called little Venice.

Residents acknowledge:

(7) "*It can be considered one of the most beautiful stretches along our coastline, where you can still find natural characteristics and also some stretches where can observe the natural dynamics of the coastal zone*."

(8) "*It is a coastal area with a beach and despite some urbanization there are still some relicts of natural areas for great landscaping value*."

Cultural Identity and Risk Culture

Most of the regions of modern Italy have rich cultural traditions, perhaps slowing down the idea of a central unified Italian state in the past. The Emilio-Romagna region is especially known as one of the wealthiest and most developed regions in Italy and Europe alike, featuring seven UNESCO World Heritage Sites (Emilia Romagna, 2020) and a strong economy due to automobile and food production.

The people of Porto Garibaldi take pride in their identity of being fishers in one of the wealthiest regions of Italy. As one resident noted:

(9) "*(. . .) the whole culture of the Comacchio area is based on fish and eel*."

While the cultural identity of the people in Porto Garibaldi is highly shaped by fishery, agriculture and touristic activities also form large parts of the sense of belonging that is anchored in daily practices. Apart from generating material wealth, these circumstances have also shaped immaterial values of the community, promoting for example entrepreneurial thinking and care of cultural tradition. Every year, festivals take place, including the celebration of the Madonna of the Sea in June with the traditional procession of decorated boats, which enter the port.

Cultural Identity and Socio-Economic Values

Porto Garibaldi holds the potential of joining the rank of iconic touristic villages and towns such as Cervia, Rimini, or Riccione. Famous Romanesque and Renaissance cities such as Ravenna, Ferrara, Modena, and Parma are relatively close by. It is also an area of strategic importance for the Emilio-Romagna region, containing, on the one hand, the largest touristic facilities in Italy while being, on the other hand, a center for many significant industrial activities. Fishing and tourism are key drivers of the socio-economic development of Porto Garibaldi. They represent the centerpiece of the local identity.

High-impact hydrological events, such as storms and flash floods affect the Emilia-Romagna coastline frequently (Armaroli et al., 2014). Coupled with intense urban development along the Adriatic coastline, dune and wetland-systems reduction are a typical sign of the progressing environmental degradation contributing to further vulnerability of the coast (Armaroli et al., 2014). In addition, human activities are intensifying vulnerability to hazards in the area. Urban development at the coastline increased significantly over the past decades, reducing dune and wetland-systems. Not surprisingly, residents noted that:

(10) "*It's an area which, especially in the northern part, was subject to quite recent urbanization*."

(11) "*It's for this reason that this area is now showing a few quite significant anthropogenic effects, especially with regards to beaches, dune fragmentation and so forth*."

At the national level, the EU Flood Directive 2007/60/CE and Marine Strategy Framework Directive 2008/56/CE are being used to map vulnerability and risk and to preserve the environment and biodiversity, respectively. In addition, the regional authorities issue planning guidelines at provincial levels through regional territory plans such as dredging of canals to avoid deterioration of the water quality in the lagoons as well as overflow of the canals. However, research on Italian planning processes points out "significant gaps between planners' intentions and planning outcomes, exemplary and ordinary planning practices. . . political and administrative cultures and practices." (Vettoretto, 2009). Accordingly, residents in Porto Garibaldi report a lack of signals from coastal authorities regarding measures to reduce the risk

of flooding to people's homes, shops and restaurants. One resident stated:

(12) "*Our structure, as well as our culture, is not integrated. We have authorities, internal departments of the region, external authorities*."

Resilience

Residents of the area are highly aware of the risks of flooding and take measures themselves to deal with risks as the following quote illustrates:

(13) "*The main hazard affecting the area is related to flooding… The whole area is widely below sea level, especially the inshore and backshore area which is highly vulnerable in the event of sea flooding, considering that these events are quite frequent now*."

In the absence of clear signals from authorities, residents became prone to testing risk reduction measures themselves. One interesting example is the *ad hoc* construction of a measure called *winter dune*. These are artificial dunes, which are only put together during wintertime to protect near shore restaurants and other establishments from damage and inundation during the usually stormy winter season. The procedure developed in the Porto Garibaldi area and seems to be unknown elsewhere. Over time, *winter dunes* have demonstrated to be useful in avoiding marine ingression (Harley and Ciavola, 2013). The elevation, width and location of a dune is based on the a resident's experience. Recently, this informal practice was regulated through some compulsory guidelines issued by the local authorities recommending certain parameters regarding heights and slopes of dunes as well as suggestions for the withdrawal of sand. However, residents are still fully self-responsible for the building of a winter dune:

(14) "*(.) the local community is very active and even proactive in undertaking actions to protect their own property and coastlines, as can be seen in the case of winter sea storms. They build their own sand dunes, to protect their infrastructure*."

RESULTS

Given the different nature of coastal risk cultures in both case study sites, suggestions for improvement of risk management in the cases are broad in scope but narrow in the way that participation of local residents seem to be underrepresented in public coastal risk planning. For Ummanz establishing communication among the islanders and the coastal authorities would be a primary measure in order to gain trust and broaden mutual understanding on costs and benefits of the certain coastal risk reduction measures at hand. Perhaps a moderated round table discussion on risk reduction measures including the visions of the islanders asking what would they support or even change could be a step forward to overcome the current stalemate situation. In Porto Garibaldi it also seems that the integration between local actors and coastal agencies is somewhat hampered and that more dialog is needed to increase the sharing of good practices to manage the coastline. This could potentially open doors to more collaborative efforts amongst different actors with the goal to develop more long term planning schemes to face disasters in the region in the future.

DISCUSSION

Role of Cultural Values in Adapting to the Coastal Risks

The above sections illustrate that the different historical development paths of the two communities, Ummanz and Porto Garibaldi, led to particular material and immaterial value sets, which find their expression in different risk cultures and narratives to cope with risks of storm floods and inundation. Based on interviews and participatory observations the following differences in the risk culture of the two communities have been extracted:

In Ummanz, the memory of past storm surges such as the 1872 flood and its impact are deeply ingrained in the collective mind-set of the islanders (see quote 2). Knowledge is transmitted from generation to generation, for instance surrounding the building of the ring wall, erected in 1873, (see **Figure 3**). Land reclamation, as well as the appreciation of the success through the creation of polder stations, are also kept alive by the chronicler of the islet. This is contributing to a sense that the residents have been able to cope with storm surges and challenges of inundation, which is an important dimension of cultural resilience. Moreover, for Ummanz, congruence can be noted between the interest of coastal protection connected to the historical ring-wall (see quote 3), which the residents hope to see repaired and adjusted to today's protection requirements, and the development of ecotourism. This can be explained by looking back at the municipality's socio-economic development path: The storm surge of 1872, the subsequent re-development of agriculture and later a breeding farm sheltered by the ring-wall, can be understood as a foundation myth, enabling the residents to live protected and comfortable lives in a remote place of natural beauty. Tourism has not been seen as a key driver of the development but rather as an addition to the villagers' identity of being farmers, cattle breeders and fishers (see quotes 1, 4, and 5). Apart from generating some modest wealth on individual household levels, this has also shaped the immaterial value of the community, promoting, for example, a sense of self-sufficiency and self-reliability (see quote 3). Ummanz is quite a conservative community in the sense of wishing to maintain these existing values, which are readily found in the land- and seascape as well as in immaterial values such as tranquility and remoteness (see quote 1). The coastal protection concept (a crossbar solution across the islet) proposed by the state is seen as a threat to the hard-won identity and immaterial values of the islanders, as many areas have been actively reclaimed from the sea (see quote 5). Ummanz, however, cannot afford the expensive ideal solution of maintaining their historic ring-wall. This results in a stalemate situation preventing risk reduction measures from being implemented at all.

In Porto Garibaldi, the main risk to residents and tourists alike is flooding from the sea and the river, as well as erosion

and induction of saltwater. Since the whole area lies widely below sea level, the population obviously is very aware of these risks since inundations caused by floods occurred frequently in the past especially during winter times (see quote 13 and 14). As opposed to the community of Ummanz, Porto Garibaldi belongs to one of the wealthiest regions in Italy. Tourism has always been a key driver of developments and represents the centerpiece of Porto Garibaldi's identity. Apart from generating material wealth, this has also shaped the immaterial values of the community, promoting for example entrepreneurial thinking (see quote 14) and investment in culture and infrastructure. Agriculture and especially fishery are of importance (see quote 9). Nature, too, is appreciated–but mostly from a material perspective rather than for the intrinsic or immaterial values associated with it (see quotes 7 and 8). The need for coastal protection is generally accepted. Protection of the community's material values as a basis for future development is a uniting force in the community. With its culinary heritage, famous restaurants, wine tasting establishments and food markets, entrepreneurs who have their establishments located near the beach or river obviously accumulated a proactive mind-set regarding the protection of their establishments over time (see quote 14).

It seems that due to the absence of clear signals from coastal planning authorities regarding measures for reducing the risk of flooding, residents formed their *ad hoc* mind-set resulting in the testing of winter dunes, hence contributing to the resilience of their community.

Table 1 captures the mind-sets that characterize the two communities and drive the development of their risk cultures, the knowledge they hold on to and the adaptive measures they undertake or stay away from.

The above-discussed findings show the implications cultural values have for the formation of knowledge and risk management in communities. In Ummanz, the residents are captured in a stalemate situation driven by outrage about proposed coastal state measures, which in their opinion would destroy important parts of their cultural heritage, including their communal identity. In contrast, the residents of Porto Garibaldi utilize the rather restrained approach which the coastal authorities are taking toward risk management to create their own, autarkic safety measures. In the Italian case, the desired future does not compromise ingrained heritage and traditions nor does it seem financially and technically unfeasible to implement own protective measures at an individual level. In Ummanz, however, the scale of the protection needed is clearly beyond the financial and human capacity at an individual household level as well as at the level of the general community. The narratives of the ring-wall, which safeguarded the islanders for generations is deeply ingrained in the present risk perception and risk culture of the residents. The specific culture and contexts in which this narrative became embedded influences the dynamics toward change and collaboration with the coastal authorities in Ummanz. In contrast, in Porto Garibaldi, a culture of entrepreneurial thinking, in addition to financial capacities, spurred intervention in form of the residents actively trying to shape a different coastal management reality.

As the cases from Germany and Italy illustrate, the effects which culture and context can have on individual and communal resilience, are not a triviality. Decision makers and planners do need to pay attention to those "cultural" details, the complexity of local conditions and their path dependencies to build trust as well as to strengthen communication between residents and implementing authorities. At the same time, they should support adaptation measures which respectfully acknowledge a community's traditions and heritage while mediating up-to-date forms of coastal protection as well as adaptation measures and enabling mutual learning.

CONCLUSION

As a major adhesion between different elements, culture is embedded in all aspects of society. A separation only enables analytical distinction between the rational and the symbolic-emotional aspects of environmental concerns. In this sense, culture is not only a positive factor, e.g., strengthening resilience, it can also prevent progress and increase vulnerability instead. The aim of the research was to illustrate how risk perceptions of residents in two case study sites in Germany and Italy, their values, interests and societal contexts, were negotiated and contested and how they, in the end, resulted in different risk management activities. The risk cultures of the people of the island of Ummanz and in the coastal town Porto Garibaldi are framed by their experiences with floods and shaped by interactions with their cultural values, economic resources and political interventions or the absence of such. In other words, communities are not uniformly vulnerable or resilient. In the case of Ummanz, the reasons for the islander's ongoing vulnerability are primarily of a socio-cultural and economic nature while in the case of Porto Garibaldi vulnerability originally seemed to be rather politically determined and eventually became partly transformed into self-organized resilience of entrepreneurs located near the shore. Hence, to a large degree, the causes and consequences of coastal risks are cultural in nature. Although there is a growing concern amongst policy makers and practitioners to support and empower capacities of communities under changing climatic conditions there is still little systematic understanding of why approaches work at local levels or not and what makes some communities resilient and others less so. Due to insufficiently understood cultural phenomena, which influence risk perception, needs and choices of measures, the concept of climate resilience has not yet reached its full potential. Recognizing the importance of local cultures in the process of developing and implementing coastal risk reduction measures and programs is therefore paramount.

Since coastal regions share particular governance and risk management approaches as well as natural resource and built environment practices, using a Climate Resilience Index, as

recently suggested by Smith et al. (2019), can support policy makers in measuring a community's resilience in relation to socio-ecological impacts of natural hazards. However, due to the possibility of a high divergence of historical and socio-cultural path dependencies, values and contexts, varying perspectives from coastal regions across countries, as documented in this research, might result in different measures to adapt to similar types of disasters I order to boost communities' resiliencies.

Recommendation

This article shows that adaptation and resilience develop on the basis of socio-cultural-economic traditions and evolutions. It demonstrates that values evolve alongside the socio-economic developments of a community, which in turn is influenced by the political and wider economic environment. In order to promote participative planning processes and through these communication and cooperation between diverging interests, it therefore pays to look at the central values that determine community identity and attitudes. Reference is necessary to local interests, values and attitudes e.g., to the coast and sea aesthesia in the two case studies under investigation determine community identity and consequently the community's ability to find and implement acceptable solutions. In order to be able to successfully plan, implement and communicate adaptation measures and strive for resilience, knowledge of historical, cultural and socio-economic development paths and key community values are essential. These need to be taken into account at every stage of planning, in close co-operation with local actors.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

Ethical review and approval was not required for the study which includes human participants, in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

The author confirms being the sole contributor of this work and has approved it for publication.

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Solastalgic Landscapes: Prospects of Relocation in Coastal Louisiana

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Globally, rapid and slow-onset socio-environmental coastal disasters are prompting people to consider migrating inland. Climate change is exacerbating these disasters and the multi-faceted causal contributing factors, including land loss, livelihood shifts, and disintegration of social networks. Familiar with ongoing disruptive displacements, coastal Louisiana residents are now increasingly compelled to consider permanent relocation as a form of climate adaptation. This paper elicits and analyzes coastal Louisiana residents' perceptions of socio-environmental changes as they pertain to relocation as adaptation and the precariousness of place, both biophysically and culturally. It investigates how these external mechanisms affect relocation decisions, and empirically expand on how these decision-making processes are affecting residents internally as well. Research methods include semi-structured interviews with coastal Louisiana residents, participant observation, and document analysis. The paper integrates literature on environmental migration, including climate-driven; regional studies on Louisiana, and disasters, with empirical, interview-based research. It is guided by theoretical insights from the construct "solastalgia," the feeling of distress associated with environmental change close to one's home. The findings suggest that residents' migration decisions are always context-dependent and location-specific, contributing to a broader understanding of coastal residents' experiences of staying or going.

Keywords: climate change, disaster, migration, Louisiana, Gulf Coast, relocation, managed retreat, solastalgia

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INTRODUCTION

This research centers on understanding the links between migration possibilities and the influence and experience of four interrelated factors: social networks (i.e., faith-based networks, civic organizations, family, cultural and heritage identities, etc.), the multi-layers of disasters (specifically hurricanes and the oil spill disaster in 2010), and place, including sense of and attachment to it. Climate change is threaded throughout and shapes all factors. Research is based upon qualitative data collection with coastal Louisiana residents who are engaging in decisions of both formal and informal relocations.

Climate change related risks and hazards, feelings of loss, and socioeconomic status arose as dominant underlying drivers within the larger themes. Residents frequently cited these factors as components of their decision-making processes. Placing residents' considerations of migration within a broader socio-political, cultural, and economic context facilitates a more nuanced understanding of why many coastal Louisianans are considering relocating.

The decision to migrate away from a place one has a long-standing connection to is inevitably complex and emotional. It can challenge both individual and collective identities (Mendoza and Morén-Alegret, 2013) and ultimately involves a (re)negotiation of oneself and others (Boccagni and

Baldassar, 2015). There is a deeply rooted sense of and attachment to place and to one another in southeast Louisiana. Yet, both are under threat, as the land disappears and communities disperse inland. As such, when the livability of a beloved place is compromised, it is often accompanied by feelings of sorrow and loss (Cunsolo and Ellis, 2018) that are not easily quantifiable.

Community migration operates through both formal and informal processes. Informal migration is a process whereby residents move individually to safer, often inland, locations as a result of multiple shocks and stressors. Such informal migrations, which may occur over several generations, often result in a gradual loss of community and sense of place. Formal migration, as discussed in this research, is a more coordinated process involving state and local policymakers who are working with a community to voluntarily relocate. Solastalgia, as a conceptual tool, permits a richer understanding of the losses Louisianans are feeling and how that subsequently affects migratory decision-making.

As an example of a formal process of a community relocation, a majority of residents of Isle de Jean Charles (or "the Island") in Louisiana are preparing to resettle together to an inland site better shielded from the impacts of climate change. The U.S. Department of Housing and Urban Development's (HUD) National Disaster Resilience Competition (NDRC) grant is funding the effort. Isle de Jean Charles is home to mostly American Indians who reside in a rapidly changing environment wherein a cascade of emotive and physical losses are occurring. Yet residents' connection to the Island remains. These deep cultural and historical bonds prompted the State of Louisiana's Office of Community Development, as the administrator of the grant, to work with Island residents to configure a way for them to keep their land and homes after relocation in order to maintain a relationship to their ancestral homeland. For many current and former residents, even those who were displaced from the Island as small children, there is a deep and emotional attachment to the land that continues today. As this sacred place further erodes and people move away, Islanders are experiencing grief and mourning (Yawn, 2020).

Following the introduction, the theoretical background section reflects the scholarly works that ground the key migratory decision-making factors emerging from the data, including the concept of solastalgia. Following this, the methods section describes a qualitative approach used to broadly gather and then distill resident perspectives on possibilities of migration in three southeastern Louisiana parishes: this paper's empirical contribution. The combined results and discussion section situates residents' experiences in their social, political, and economic contexts, highlighting the blending of the many multi-scalar influences in migratory decision-making processes. It provides an articulation of criteria as cited by interviewees grappling with the emotional ramifications and underlying meanings of these decisions in a dynamic and shifting place. The resettlement of Isle de Jean Charles completes that section. Concluding, the remainder of the article highlights the key findings and empirical contributions, the broader implications of these findings and their transferability.

Theoretical Background

Migration and environmental change are a "research frontier," widening the understanding of migratory patterns in scale and complexities (Adger et al., 2015, p. 2). Despite robust discussion and theorizing in the arena of environmental migration (Castles et al., 2014) there remains a lack of empirical accounts of the role of environmental change (and other prevailing drivers) in migration (Kelman et al., 2017), and until recently, little attention paid to sense of and attachment to place (Dandy et al., 2019). Accordingly, this article focuses on empirical accounts of often emotion-laden regional migration decisions. It offers opportunities for a more wide-ranging depiction of migration dynamics that go beyond census data or population numbers (Dalbom et al., 2014; Hauer et al., 2019). Highlighting the sentiments and perspectives of those affected by ongoing degenerating environmental conditions is vital for understanding migratory processes and can only be found in talking to the residents themselves (Kelman et al., 2017). They are also often overlooked in migration studies (Barrios, 2014; Boccagni and Baldassar, 2015).

The decision-making surrounding migration is occurring in places where multiple influences and socio-environmental networks intersect; where people derive, construct, and re-construct their identities, all while establishing and maintaining both human and non-human relations in a complex landscape (Hedberg and do Carmo, 2012; Pellow, 2016). These interrelationships between place and migration are complex and stand to benefit from deeper investigations (Hess et al., 2008; Hugo, 2008). How people come to interpret climate change risks from their specific cultures and places remains inadequately researched (Tschakert, et al., 2017).

Place is a structure that subsumes both human experiences and the material world in which those experiences happen (Casey, 1997). It is one of numerous dimensions of risk correlated to hazardous environmental exposures, including climate change, which has uneven spatial distribution among places (Dolan and Walker, 2006; Intergovernmental Panel on Climate change (IPCC), 2014) and race and class lines (Marino, 2018). Relatedly, sense of place is a multidimensional concept that embodies emotions, beliefs and behavioral actions specific to particular geographic settings (Tuan, 1974). These interconnections of often-everyday experiences vary in forms of expression, emotion and strength and can be so influential as to be an integral building block in the construction of individuals' identities (Massey, 1991; Mendoza and Moren-Alegret, 2013). Place attachment is the meaning conferred on the felt connection with place. Various authors (Burley, 2010; Jenkins, 2016) have identified the distinctive attachment to place for Louisiana residents. Some residents have such a strong sense of place that migrating embodies a forfeiture of their way of life, not simply a place to live (Jenkins, 2016).

Social networks are a component of understanding the emotional ties to place and influences the decision to migrate (Bronen and Chapin, 2013). Whether relocation is forced or voluntary, multiple disciplines show that it creates substantial stress for those involved, disrupting or impeding social networks (O'Sullivan and Handal, 1988; Riad and Norris, 1996; Castles,

2003; Dun, 2011). The stress can be related to shifting identities, including individual, as well as landscape and population alterations (Oliver-Smith, 1991; McHugh, 2000; Williams, 2006; Klinenberg, 2016).

Migration outcomes may benefit an individual or household, but can have adverse effects on the adaptive capacity of the community where they once lived. There is limited systematic research on multi-scalar impacts of adaptive migration on both those who migrate and those who do not (Schade et al., 2016). Barrios (2014) and Browne (2015) emphasize the crucial presence of social relations among spatially close friends and family during relocation and resettlements. When hardships such as deteriorating environmental conditions or a large storm place an undue burden on residents, many people report turning to their social networks for assistance (Adger et al., 2015; Aldrich 2012; Bodin and Crona, 2009; Folke, et al., 2005; Tompkins and Adger, 2004). This is a common response in coastal Louisiana communities (Colten et al., 2012; Colten et al., 2015).

Such is the case, for example, of migration from the small Island nation Tuvalu. Keeping social groups together demonstrates this is a significant motivation for residents who must contend with dramatic declines in living conditions due to sea level rise and other small and large-scale disasters (Shen and Gemenne, 2011). A similar concern emerges for Native Alaskans in rural communities who are attempting to relocate themselves due to erosion of the land surrounding their village (Marino, 2012), as well as for the residents of Isle de Jean Charles, who will largely relocate together, maintaining their spatially close social relations to one another.

Research underscores that decisions of migration are influenced by environmental factors, but ultimately shaped by a complexity of often-simultaneous forces, including social, political-economic and cultural processes (Black et al., 2011; Oliver-Smith, 2012). This paper pays particular attention to the socio-environmental factors specific to the Louisiana coast influencing residents' migration decisions in the geographically bounded places they currently reside in or may in the future. The majority of residents interviewed expressed their desire to remain *in situ* (Simms, 2017).

Increasingly, calls to examine migrations within a broader, more holistic context, particularly when it comes to an inclusion of political and socio-economic processes, are imperative (Mendoza and Morén-Alegret, 2013; Barrios, 2014; Greiner and Sadapolrak, 2016). Understanding that social inequalities are present as both preconditions and outcomes of migration prompts significant questions about the effects and processes of migration. Research that incorporates these understandings can inform the prevention of longstanding inequalities from simply being repackaged and re-emerging in a different form (Schade et al., 2016).

The emotional dimension of the connection between socio-environmental degradation and migration possibilities experienced by residents may be explained by the place-based concept "solastalgia" (Albrecht, 2005). Defined as the distress experienced when one's sense of place is under assault due to degrading environmental conditions of a home region, this concept is applied throughout this research. Etymologically, the word refers to pain surfacing due to a reduced ability to draw 'solace' from one's surroundings (Albrecht et al., 2007). Solastalgia is often signified by a struggle to find solace in a place where one once found comfort; it is a feeling of homesickness when still at "home." These feelings are often connected to a sense of powerlessness and an inability to influence the social and biophysical transformations causing the distress. Amidst coastal Louisiana's acute and slow-onset disasters, the subsequent widespread economic, cultural, political, and social multi-scalar effects, many residents are feeling emotions that can be considered symptomatic of solastalgia, while also contemplating relocating themselves and their families.

As described in a study conducted with residents living in an area recently experiencing a destructive forest fire, researchers explore the psychological connection between the landscape and human health. They found that the losses caused by the fire instigated feelings of grief, violating the endemic sense of place for those living in the area. For example, over 71% of residents agreed or strongly agreed with the statement, "I feel like I have been grieving for the loss of the forest affected by the Wallow Fire" (Eisenman et al., 2015). Wildfires, hurricanes and technological disasters such as the 2010 oil spill explosion, dramatically change landscapes. Solastalgia is an effective framing mechanism that can illuminate the feelings arising from the loss of familiarity in places where people once sought comfort and connection.

Solastalgia is grounded in the sense of place and place attachment constructs, permitting an exploration into deeply interconnected, dynamic, and nested social-ecological systems. This concept assists in reflecting on and analyzing how residents' identities are interwoven with place and serves as a vital category of analysis in understanding how this affects migration possibilities.

METHODS

This article combines four sets of formal, in-depth interviews with 110 Louisiana residents in three counties ("parishes" in Louisiana) conducted between 2012 and 2016. Interviewees told their own histories and experiences in response to open-ended interview questions broadly focused on the social effects of land loss and coastal hazards. Data collection instruments included semi-structured interviews, focus groups, participant and non-participant observation, fieldnotes, thematic coding and content analysis. Combining analysis of primary and secondary sources provided broad-based insight into the implications and further effects of migration possibilities for coastal Louisiana residents.

In-person interviews, rather than alternate qualitative methods, i.e. census surveys or questionnaires, were selected to accommodate a broader and more nuanced array of experiences and views (Dunn, 2005), including facial expressions, body language and emphasis of certain words. The interview as a key qualitative method assists and deepens the understandings of the ways people relate to place, social networks, and identities (DeLyser and Sui, 2013). They facilitate refining the pieces that make up a process, i.e., a decision to leave one's home. Residents

responded to interview questions largely in story form. Storytelling is a personal experience narrative (Denzin and Lincoln, 1994), and should be seen and interpreted as interactive text (Miles and Crush, 1993).

In analyzing the data, the process was inductive, drawing upon concepts underscored by the interviewees and examined from a "bottom up" approach. The qualitative analytical techniques of thematic coding and content analysis were merged. Thematic coding included compiling the interviews and identifying emerging themes and concepts. Following this, content analysis was employed to code specific themes, phrases, interpretations, ideas and perspectives (Suchan and Brewer, 2000).

The first interview set, conducted between February 2012–June 2013, Terrebonne Parish residents were asked to respond to questions about their observations of socio-environmental change, specifically land loss, in their parish. The interviews centered on the Terrebonne Parish marsh and land restoration plans as laid out in Louisiana's Comprehensive Master Plan for a Sustainable Coast [Coastal Protection and Restoration Authority of Louisiana (CPRA), 2012)] and how interviewees anticipated the plans would affect them and their families. In the second set of interviews (October 2013–February 2015), residents were asked questions about resilient and ongoing social practices (Colten et al., 2012) taken up by mobile and immobile residents. The interviews explored the role of social networks in the anticipation, preparation, reduction of vulnerability and/or recovery from disturbances, such as hurricanes and the 2010 oil spill disaster (Colten et al., 2015). In the third set, interviewees who had direct experience with the 2010 oil spill disaster were sought out to elicit responses to "changing social effects," i.e., community livelihoods, health and environmental changes. The final interview set sought information about specifics related to migration. Both residents and those with professional/public roles connected to relocation/resettlement efforts were interviewed. Residents were asked about their social networks as related to the socio-environmental changes in their surrounding communities. Both groups were asked their thoughts or ideas regarding local migrations, and the factors they see as anchors to remaining *in situ* or conversely, factors acting as "tipping points" to force migration.

These four broad categories provided a loose framework of questions and allowed interviewees to provide the content. The sets of interviews centered on varied, although interrelated themes. The shared themes threading through each of these sets of interviews are a sense of and attachment to place; family, friends and social institutions; identities rooted in the socio-environmental practices of residents in and around their homes; and intertwinings with the possibilities and practices of migration. Combining these interviews assists in telling a broader story of what factors affect migratory decisions and how these decision-making processes are affecting residents.

Interviewees

A nonprobability sampling technique commonly referred to as "snowball sampling," was employed for contacting and interviewing residents. The majority of interviewees lived in Terrebonne Parish (63%), while others lived in Lafourche Parish (24%), or were current or former St. Bernard Parish residents (14%). (**Table 1**). Interviews were conducted with individuals exemplifying the principal ethnic groups, sexes, and various income categories. Most of the interviews were conducted in either the residents' offices or homes. All interviews were recorded. The majority of interviewees had lived most or all of their lives in their respective parishes, experiencing hurricanes, land loss, and/or the 2010 oil spill disaster. In most cases, the research participants had experience with all three. Interviewees held a variety of occupations and identities including state and federal government officials, industry employees, health workers, academics, community-based organization leaders, activists, journalists, bankers, oyster, alligator and wetland plant farmers, crabbers, fishers, small and large business owners, oil workers and others. Occasionally an interviewee held more than one of these roles. Biophysical and socio-cultural changes are rapid and ongoing in these communities and migration is something that a number of residents interviewed think about and discuss regularly.

TABLE 1 | Study parish populations and the number of interviews conducted in each one.

Case study parish	2019 population	# of interviews
Lafourche	97,614	26
Terrebonne	110,461	69
St.Bernard	47,244	15

Interview Sites

The three Louisiana parishes wherein interviewees reside, Terrebonne, Lafourche and St. Bernard, encompass and are shaped by the Gulf, wetlands, bayous, and rivers, chiefly the Mississippi and its distributaries. (**Figure 1**). Rivers and their freshwater and sediment are integral to adding and nourishing land and cultural traditions across these parishes. Economies here are linked and dependent on coastal resources, including commercial fishing, shipping, and oil and gas and supporting industries. In Terrebonne, more than 85 percent of the parish is water and wetlands, with freshwater marsh in the northern areas, brackish marshes further south, and saltwater marshes near the coast. Lafourche, to the east, is 28 percent water [Coastal Protection and Restoration Authority of Louisiana (CPRA), 2017], alternatively.

Residents of St. Bernard and Terrebonne parishes could be among the first U.S. regions to see federal financial support removed because of increased federal disaster spending (Flavelle 2016). They are among a small number of parishes/counties with the highest number of per capita households requesting disaster assistance more than once since 1998. Specifically when it comes to repetitive loss claims, Louisiana ranks at the top. With approximately 70–80 percent of coastal homeowners foregoing flood insurance, Terrebonne has 2,000 repetitive

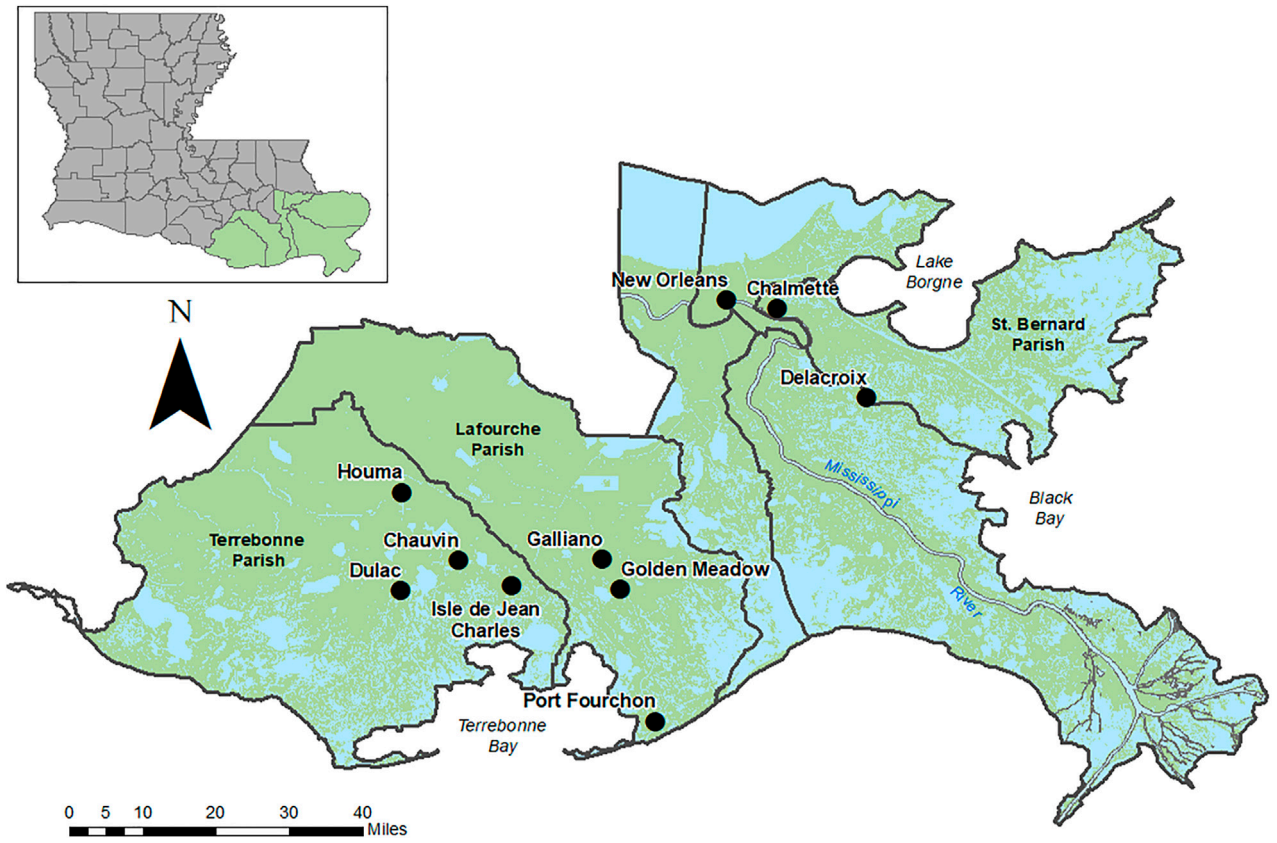

FIGURE 1 | Map of southeast Louisiana showing study parishes and related landmarks.

loss properties, St. Bernard 1,207 and Lafourche Parish has 489 (among the lowest) [Coastal Protection and Restoration Authority of Louisiana (CPRA), 2017]. Lafourche Parish has not been immune to hurricane damage, flooding, subsidence and coastal land loss, but compared to Terrebonne and St. Bernard parishes, the damages are considerably less.

The geographies of these three parishes play a significant role in past, present and future migration patterns. For example, the extensive hurricane protection system in Lafourche is a principal reason many interviewees claim that neither they nor others in their social networks are planning to move. Many Lafourchians instead link migration changes to the ebbs and flows of the oil industry. The lack of a comprehensive hurricane protection system is a key factor in why Terrebonne Parish interviewees are considering moving or expressed concerns about staying. Many of them impart hope into faster and better-funded construction of the Morganza to the Gulf Structural Protection System. Northeastern St. Bernard Parish, where the majority of parishioners reside, is largely protected by a hurricane and flood protection system. In 2006, a year after Hurricane Katrina, more than 50,000 of the approximately 67,000 residents of St. Bernard Parish were living in different parishes (Louisiana Recovery Authority, 2006). In 2021, it has still not returned to pre-Katrina levels.

RESULTS AND DISCUSSION

The Louisiana Coast, A Place of Uncertainty, Stressors, and Beauty: "There's No Status Quo for Coastal Louisiana—It's Always Changing"

As coastal residents contend with the deeply pervasive anxieties and uncertainties embedded in the COVID-19 pandemic, historically high unemployment rates, and historically low oil and gas prices, a global recession, and a record-breaking Atlantic hurricane season, conversations of migration are undoubtedly increasing. Will this be the year we will have to leave?, many will ask themselves.

Louisiana ranks third in the United States for percentage of residents surviving below the poverty line (West and Odum, 2016). Confidence in Louisiana's oil and gas industry as a reliable source of income and employment has declined in recent decades (Austin, 2006), with a general upswing in an inability to maintain natural resource–based livelihoods (Marks, 2012; Horowitz,

2014). In interviews, residents emphasize the necessity of a multitude of livelihood strategies, changing understandings of the landscape, profound feelings of nostalgia, and the negotiations and compromises they are making both with themselves and one another.

In all of this, there lies an overarching theme: uncertainty. Most coastal Louisiana residents are well-acquainted with living in a persistently unpredictable context. Combined with longstanding stressors related to losses of social networks and financial resources, attempts to gain stability in unresolved life circumstances are referred to as "chronic disaster syndrome" (Adams et al., 2009). This in itself is a stressor, with some residents indicating this accumulation can be a "tipping point" in the ultimate decision to relocate.

Whether older and retired, middle aged and working in the oil fields, or younger and unable to finish high school, the research participants, would most often first illuminate the positive aspects of the places they live. They use descriptors such as "magical," "a playground," what "makes (my dad) feel alive," and being "mesmerized by the sheer beauty of the bayous and lakes." Contemporaneously, they share concerns and fears that "we will all be waterfront property" (resident interview, 20 July 2015). A member of a family owned maritime shipping business, quipped, "the close proximity to the Gulf? It will become a hazard to our livelihoods" (resident interview, July 29, 2015). These contradictory descriptions and peoples' relations to them capture the intensely strong connection to the region, while also recognizing the inevitable changes embedded in an increasingly uneven landscape of risk. As one Terrebonne Parish resident working at a local community center predicted for her region: "I don't think that a lot of people in the parish know how they're going to be affected in the future. And then it will be too late" (resident interview, July 27, 2015). Over the last twenty years, more and more migrations are occurring due to socio-environmental stressors, disasters and climate change.

Every day Louisiana's Gulf Coast undergoes a physical, social, and cultural reshaping. In tandem, so do the associated meanings and everyday practices residents perform in relation to the places they live. A social worker explains, "the oil spill affected family stressors—financial situations, people fishing or shrimping. It affected everyone and trickled down to the families, grandma and grandpa and mom and dad and the kids. The culture is shifting and changing" (resident interview, July 24, 2015). Places are awash with meaning, and incorporate both existential aspects as well as emotional connections (Mendoza and Morén-Alegret, 2013). They also play a central role in the development of one's identity and social connections. When processes of change, such as coastal land loss occur in a cherished place, peoples' identities are affected, too (Burley, 2010).

Alongside shifts in identity, a changing sense of place occurs. A disruption in the links between sense of place and identity can cause negative psychological and health effects (Lewicka, 2013). As residents witness their burial grounds, playgrounds, and homes erode into the Gulf, feelings of solastalgia are triggered, eroding place-based identities (Tschakert et al., 2013). As that connection corrodes, and more becomes uncertain, the pressure to migrate can intensify.

Terms such as climate change, migration, moving, relocation and resettlement can be contentious subjects in these parishes. This opposition is related to the main themes in this article—a robust sense of place and difficulty severing ties with the associated identities to the place and social networks therein. Many residents would speak about others whom they knew to be considering migration rather than themselves; or as one resident, a self-described "lifelong volunteer and community advocate" phrased it, "people won't say they're thinking about moving, but you better believe that behind closed doors they're talking about it" (resident interview, June 6, 2013).

Climate Changes on the Coast: "Canary in the Coal Mine for Climate Change"

Coastal Louisiana is experiencing the highest relative sea-level rise (RSR) and subsidence rates in the United States (Marshall, 2013). Sea levels in Grand Isle, LA, are two feet (0.6˚m) higher today than in 1950 [National Oceanic and Atmospheric Agency (NOAA), 2020], with the entire coast seeing more than an eight-inch (20 cm) difference from 2006 to 2011 [National Oceanic and Atmospheric Agency (NOAA), 2012]. An NGO director identifies these escalations as "an inevitable stress for the beginning of hurricane season. There's a common sense of anxiety that never existed before ten years ago[1]" (resident interview, August 6, 2015). The distress and losses triggered by socio-environmental changes to the places people love can result in cumulative mental, emotional, and spiritual health impacts (Albrecht, et al., 2007; Askland, et al., 2018). These impacts can not only affect individuals, but can also lead to community distress (McNamara and Westoby, 2011). Residents often expressed their thoughts on the improbable viability and connectivity of their communities, while others hoped that once protection measures such as large-scale levees were put into place, their communities could be sustained, and perhaps grow, especially if oil and gas prices go back up.

Most interviewed residents do not frame migration possibilities in terms of climate-induced changes, yet will cite stronger storms and land loss, both exacerbated by climate change, as reasons to consider it. A handful characterized migration considerations as happening under the web of a "strong climate signal" (Burkett, 2016), including an elderly resident who had lived all his life in lower Terrebonne Parish. He noted: "what's happening to us in south Louisiana is going to happen to every low-lying coastal community throughout the world if global warming is as significant as everybody says that it is" (resident interview, November 11, 2015). The Intergovernmental Panel on Climate Change (IPCC) projects that as global mean sea levels rise, historically uncommon extreme sea level events i.e., currently hundred-year events, will be annual events worldwide for most low-lying coastal communities by 2050 (Intergovernmental Panel on Climate Change IPCC, 2019). Another resident, a licensed social

[1]Ten years ago was 2005, the year Hurricanes Katrina and Rita caused widespread damage across the Gulf Coast.

worker who continues to work in Terrebonne Parish, but moved about ten years ago to upper Lafourche Parish, notes that the effects of climate change are already here. He says, "an increasing concern is climate change. We are having more intense hurricanes when they do come" (resident interview, July 17, 2015). Sans major adaptation efforts, risks related to relative sea level rise (land erosion, salinization and flooding) along all low-lying coasts are expected to significantly increase by the end of the century.

A Tipping Point: "Sitting Ducks"

The magnitude, coupled with the sheer number of disasters to affect southeast Louisiana is profound. Residents' acknowledgement of a potential tipping point indicates that there is certainty in the uncertainty, or, put another way, it isn't a matter of if, but when relocation will be inevitable for them. The uncertainty itself, however, did not appear to be a tipping point or a key reason to consider migrating. Residents identify myriad other "tipping points" as well as the overall vulnerability of their region. While a number of residents returned to their homes after hurricanes Katrina and Rita in 2005 or Gustav and Ike in 2008, many now describe their current position in their homes as being precarious, or, as one resident, put it, "they're sitting ducks and they're gonna flood again" (resident interview, July 7, 2015). The tipping point could be an instance of widespread flooding, an emotional incapability to adapt, a financial inability to repair one's home (again) following a storm, or being "one storm away." Or it could be insurance-related, as described by a church volunteer in a focus group in Houma, "insurance is very high, I may have reached the tipping point with insurance. I'm working so hard right now; I've just got to survive. We keep our prayers up" (resident interview, November 6, 2015). Despite the significance of relevance to policy development, climate-induced socio-economic tipping points remain under-researched (van Gingkel et al., 2020).

Scaling up from the individual to the parish level and in the context of multi-disasters, one public official in Terrebonne Parish stated, "we are one major event away from being gone. We are dead without half our population to draw in the numbers" (resident interview, June 15, 2015). This comment reflects the fear that many residents expressed in terms of being in a precarious and unstable situation at both the individual and parish level. As a solution, another public official offered, "we need to stay away from disasters and focus on developing what we have. The joker in the deck is if we have another disaster and we haven't done enough to reinvent what was lost" (resident interview, July 28, 2015). When asked if he thinks that he and his family will continue to live where they do, he sighed, and said, "they (his kids) want to live here, too. I don't have any intentions of moving, but if it comes to it, I may have to." For some residents, there is a deep sense of grief and heartache in conceding that a tipping point for migration exists.

Solastalgia acknowledges the tension and often, sadness, inherent in considerations of migration. The interaction between treasured places and what has been lost due to uncontrollable forces was a common interview theme. One resident, a single mother and school administrator, describes what her bayou town once felt like to her: "When I was a kid in Montegut, it was so clean. There were flowers everywhere; it was so beautiful and pristine. The storms are taking that away" (resident interview, October 20, 2015). In describing Montegut the way that she remembers it, this resident is re-creating and imagining spaces and places that have changed, are infused with memories and her sense of self—all drawn in large part from the past. Peoples' affective relationships to the landscape are dynamic, often emotional, and ties can run deep. They are nested collections of human experience, where people are intimately knowledgeable about the traditions that made it possible for their families to make their lives on the coast.

Social Networks: "I Want to Move Back"

Social networks heavily influence residents' thought-processes and decision-leanings of whether to remain in place or migrate more than ten miles from their current residence. They also often serve as survival tactics in the face of hardships; generate and build trust; facilitate social mobility; offer business opportunities; and dissuade, or persuade residents to eventually migrate. The connections and disconnections between and among residents and their churches, their grandbabies and employers, their boats and the money gained from catching and selling shrimp, but also feeding one's family with the day's catch, are contingent on social networks and shape migrations.

Social ties are robust in these three parishes. In asking an offshore oil employee born and raised in Houma to describe his community, he said, "Houma is a family type community with a strong connection between family and friends. That's a tight seal connection there, too" (resident interview, July 16, 2015). One possibility for the "tight seal connections" was described by another resident as key to subsistence. When asked why he thinks social networks are so important in coastal Louisiana, he sums it up in one word: "Survival. We have it ingrained in us that we have to depend on each other for survival" (resident interview, August 5, 2014).

Resilience is frequently operationalized through social capital (Mayer, 2019), and as these relationships weaken, residents' recovery and re-stabilization from disasters also suffer. Disaster scholars have shown the devastating consequences of the dissolution of social networks, which earlier had served to maintain levels of confidence when facing uncertainty (Chamlee-Wright, 2010; Browne, 2015).

The places described by residents often serve as nodes wherein social interaction happens (Castells, 1996). These nodes can operate similarly to magnets, pulling in members of social networks. Indeed, it is the places where people come together and connect that enable place-based social networks to gain strength. Residents consistently identified their social networks, whether places of employment, community-based organizations, or school environments, as determinants of staying or going, such as these two differing statements from a Lafourche librarian, born and raised in the parish, and a Terrebonne public official, respectively: "My family is here, I wouldn't move" (resident interview, July 13, 2015) and "I have a son here with kids. If he goes to Houston I will go too. . . I have to be with family, you know" (resident interview, July 10, 2015).

Social networks play a role in available services, resources, and support groups used to meet the needs, social and otherwise, of residents. In order to avoid dissolution of these support systems as people choose migration as adaptation, social networks must adapt as well.

Social networks not only are key factors in the decision as to whether or not to migrate, but where and how to migrate due to environmental circumstances. (Brown, 2002; Airriess et al., 2008; Cheng, 2009; Curran and Saguy, 2013; Bankston, 2014). A homemaker in an interview focus group, explained that she continues to live in Chauvin because her family also resides there. But, "once they're gone," she said, gesturing to her parents-in-law, "I'm leaving. Going further up" (resident interview, August 5, 2014). This communication lays plain the force of social networks in many of these residents' lives. Another young resident, attending college in New Orleans, affirmed the power of social networks in his rationalization of why he hopes to return to Terrebonne Parish where he was raised. Explaining, "I want to move back because of my family history. I want to continue working where my grandfather works, my great-grandfather worked and my great-great grandfather worked. It's very humbling to keep on with traditions and ways of life in that way" (resident interview, November 11, 2015).

This 19 year old resident spoke strongly and proudly of the place and longstanding familial connections where he was raised, citing his grandfather and mother for instilling in him the importance of maintaining these connections. "I am who I am today because of my grandpa. It's why I take pride in where I'm from and our heritage and have such an interest in what it was like back then" (resident interview, November 11, 2015). The social networks this young resident is referring to are not just ones existing in current time, they are ones where family members have passed away, yet still maintain significance and influence long after their deaths. One resident, an insurance agent living about a stone's throw from where she was born, clarified, "people want to live where their ancestors were and where their roots are" (resident interview, July 31, 2012). These are networks rooted in the places where these families were born and raised. They are part of the reason residents struggle with the decision to leave and feel a nostalgia for the way things once were, despite a preponderance of other compelling reasons to relocate away from the coast.

Similarly, in identifying place as a structure that subsumes both human experiences and the material world in which those experiences happen (Casey, 1997), a Terrebonne Parish retired commercial fisherman, describes these similar connections, while also stressing the critical link between food and loved ones in strengthening bonds: "the environment provides the opportunity for a connection to your family and your friends. Because how often do you go fishing or shrimping and then have a meal or crawfish boil? A lot of it is tied to what the opportunities the environment provides to the people" (resident interview, November 11, 2015). Food, particularly local harvests, serves as an avenue through which residents connect, strengthening and building their social connections.

Social networks take into account both human and non-human factors, facilitating the flows of activities and knowledge between places (Hedberg and do Carmo, 2012; Pellow, 2016). Humans and non-humans are each embedded in these networks, determining which resources are desirable and accessible and when (Zoomers and van Westen, 2011), and ultimately concluding if migrations are even a viable option. When asked if he would consider relocating, an elder resident of Isle de Jean Charles explained that his "preference is to stay put, stay home. But, if we can stay together as a tribe to move, I will consider moving to be with them" (resident interview, August 17, 2012).

Social networks are complex and multi-varied. Residents rely on strong, tight-knit social networks and have a fierce attachment to the place they live. They are cognizant of the multiple disasters they have experienced and challenges this has already wrought, including disbanding some of their social support systems.

Multiple Layers of Mental Health: "That was the Biggest Thing—A Lot of Depression, Anxiety and Stress"

Residents contend with multi-layers of disasters, whether slow-onset, such as land loss; acute, as in the destructive aftermath of a hurricane, or in-between, such as the oil spill disaster in 2010. The oil spill disaster in particular engendered intense and cascading social effects and stresses including navigating the claims and litigation processes, unpredictability of seafood stock and market viability, and cleanup. Further exacerbating state and parish budget woes and delaying new industry-related investments, job losses numbering in the thousands soon rippled through the state (Thompson, 2015). At the height of the disaster, when the well was uncapped and about a million gallons a day were spewing into the Gulf, several residents spoke about their fear of permanent displacement. One interviewee, a former nurse and parent of three children, told me "(our child) is asthmatic. We thought that we'd have to move" (resident interview, June 15, 2015). Residents reported that the emissions from on-site burning of surface oil created inhospitable conditions for some locals. A barbershop owner reflected on the cumulative impacts his community had faced, "Sometimes we think we're leaving. It's very emotional. And (we feel) anger. Because this is our home!" (Resident interview, June 15, 2015).

A number of interviewees, particularly those involved in mental health services, mentioned the toll repeated disasters and their resultant crises take on residents. As with climate change, multiple disaster exposures are associated with decreased mental health. Both can act as "risk multipliers," incidentally setting off or exacerbating preexisting health conditions (McMichael, 2017). The culture of risk residents contend with is ingrained into their lives and is bound to generate intense effects in everyday social life (Cope et al., 2013).

When combining vulnerabilities correlated with age, ethnicity, and poverty or low-income status, the multilayers of multi-disasters are even more acute. One resident, who was in current conversations with her partner about whether to move closer to the coast to be nearer to their parents, said, "we're not doing a good job of facing those challenges (the effects of climate change including stronger storms and sea level rise) in a way that shows that people can

continue to live in those communities" (resident interview, July 24, 2016). Much of the coastal population is above the poverty level, but many just barely (Colten, 2017). Thus, they are at greater risk of an increased economically disadvantaged situation if there are disruptions due to intense tropical weather, restoration projects that impact the habitat of the resources they pursue, flooding of their communities, or sustained economic troubles, such as the pandemic. One resident, a former non-profit director, offers some advice: "We need to address those who are so vulnerable in those communities. I think that the safer you make everybody in a community as a whole, hopefully that's fewer resources on the back-end that you're going to have to spend to deal with devastating situations" (resident interview, November 11, 2015). Providing opportunities for residents to make decisions of adaptation that are financially and socially supportive will facilitate more secure futures for families on the brink (Cardona et al., 2020).

In 2010, the oil spill disaster quickly revealed how a scenario could embody multiple, interconnected interests and differential power relations. The spill brought to the forefront a long-occurring uneven relationship that for decades placed residents at the mercy of global economic instabilities. Residents spoke of a sense of environmental injustice happening to the surrounding human and non-human ecosystems, contributing to feelings of displacement without leaving home. Combined with place-based limiting factors such as land loss, poverty, climate change, sea-level rise, stronger and more frequent tropical storms, the lack of control over one's livelihood, home and at times, family, can be debilitating.

Many residents spoke of a sense of helplessness and uncertainty at the time of the oil spill disaster not experienced before. One interviewee, retired, but an active volunteer at his local community center and church, spoke for his fellow Terrebonne Parish neighbors, saying, "it was in the back of everyone's mind—am I going to be able to live the rest of our (sic) lives here?" (Resident interview, December 3, 2015). Technological disasters, such as the oil spill disaster, generate more uncertainty than other disasters, i.e., hurricanes (Baum et al., 1983). This is attributed to the seeming loss of control contrasted with a lack of control before, during, and after a hurricane (Palinkas, 2012). The unknowns surrounding the oil and dispersants' short and long-term effects interwoven with the dramatic transformation of a cherished place affected its value as a source of solace.

Louisiana coastal communities face a "triple exposure" when overlaying technological hazards onto climate change and global economic uncertainties (Colten et al., 2015). Residents are largely unable to have a meaningful say about the ongoing transformations of the bayous and marshes occurring in and around their homes. This can lead to a breakdown of relationships between identities and the socio-environmental deterioration in and around their homes.

Climate Justice: "People are Here Who Don't Have the Resources to Leave"

This research explores not only the decisions of those positioned to consider migration, but also those who are rendered immobile through underlying inequalities. Those most socially vulnerable to the challenges of living along Louisiana's coast, particularly with current predictions of sea-level rise, are disproportionately socially disadvantaged Americans (Martinich et al., 2013). (**Table 2**). Many of these communities are beset by deep-rooted and longstanding conditions of political disempowerment and economic disenfranchisement, thereby creating loftier obstacles for adapting to socio-environmental changes (Piguet, 2011; Jurjonas and Seekamp, 2019; Siders, 2019), and a more limited range of adaptive options (Jurjonas et al., 2020). A former resident of Terrebonne Parish and current employee of a non-profit coastal advocacy group noted, "I think that some of the people still left (in lower Terrebonne) are the ones that really can't leave, they don't have the money, they have a boat in their backyard, those kinds of things" (resident interview July 11, 2014).

TABLE 2 | Poverty rates of study parishes and national averages in recent years.

Year	US % Poverty	Louisiana % Poverty	St.Bernard % Poverty	Terrebonne % Poverty	Lafourche % Poverty
2019	10.5	19.0	19.2	19.0	17.5
2015	13.5	19.5	20.4	20.1	14.1
2005	13.3	20.2	17.3	18.2	17.7

It is the impoverished and marginalized communities who have contributed the least to climate change. A recent Oxfam study found that over the last twenty-five years, the richest one percent of the global population contributed double the amount of carbon as the poorest fifty percent did (Berkhout et al., 2021). Yet, it is these populations that are disproportionately finding themselves in harm's way, both though adverse landscape deterioration or mental health impacts (Hayes et al., 2018). Socioeconomically marginalized and communities of color are at higher risk of solastalgic feelings because the regions in which these populations live are typically more at risk to environmental degradation. Southeastern Louisiana lands, assets, cultures, and resources are severely threatened due to the contributing effects of climate change. The National Climate Assessment (2014) indicates that the Gulf Coast will undergo an increase in extreme and intense tropical cyclones, intensifying the risk of adverse effects from future coastal hazards.

Invariably, as these hazards increase, prompting tens of billions of dollars in damages and corresponding FEMA and insurance claims, these repeated claims will affect the tenuousness of residents' place along the coast. As one resident of Lafourche said: "the geography of where you live, coupled with poor education is a major factor in terms of environmental justice. And high poverty makes the community vulnerable" (resident interview, February 22, 2012). Indeed, coastal Louisiana is a place in which numerous claims of socio-environmental injustices abound (Lynn et al., 2013; Bullard et al., 2016).

The structural barriers and complex bureaucracy of applying for and receiving post-disaster assistance from FEMA can hit poorer and more marginalized families the hardest (Browne et al., 2015). These cumbersome processes can create multi-scalar conflicts, including conflicts with oneself. As described by a

Catholic priest in Houma, "it was difficult to go back and rely on others and have to just depend on other people when you're used to being so self-sufficient. You have to humble yourself and reach out to people and this was really hard for people" (resident interview, July 23, 2015). Many other interviewees expressed frustration at maneuvering the formal recovery processes post-storm, and instead rely on the more informal community social support systems.

These circumstances further make the case that migration as adaptation must be more holistically integrated into climate risk adaptation policies and funding (Adger et al., 2018). Furthermore, more research is needed to understand the social and cultural components, including the resilient practices (Colten et al., 2015), intangible, cultural values (Henderson and Seekamp, 2018), and heritage preservation (Browne, et al., 2015) of marginalized residents who are adversely affected by climate change. These assessments must go beyond economic dimensions (e.g., economic assessment, cost-benefit analyses) (Ghahramani et al., 2020).

The "choice" of whether to migrate or stay put is not a decision that everyone is able to make. Lower Terrebonne and Lafourche parishes are in the "V" and "VE" flood zones—the most hazardous flood zones accompanied with the highest flood insurance premiums. Flood insurance, particularly for coastal areas, needs a substantial overhaul (Craig, 2019). Because many residents of these areas are low-income, they cannot afford the insurance premiums, post-disaster loans, or renting somewhere while the old house is fixed. The consequences are disparate impacts on marginalized communities (Jurjonas and Seekamp, 2019). As one resident of Houma, a lifelong public official whose home is in the AE flood zone grumbled, "my insurance has gone from $1,200 a year to $7,000 a year. It's ridiculous. And there's a lot of people here who are just going without flood insurance because they can't afford it" (resident interview, July 17, 2015). In addition, selling a home in a hazardous flood zone that is not raised to an elevation to keep flood insurance rates reasonable can be difficult to impossible. A home cannot be sold or bought with a federally backed loan if the flood insurance will not transfer.

To address some of those disproportionate impacts and plan for intensifying climate change effects, the U.S. Department of Housing and Urban Development (HUD) awarded the state of Louisiana $92 million in January 2016 in a National Disaster Resilience Competition. The funded projects seek to holistically address community resilience by integrating risk planning with stormwater management, culture, economic development, housing and other key components of accounting for a changing place. There are ten resident-chosen Louisiana's Strategic Adaptations for Future Environments (LA SAFE) projects which are ongoing and in varying stages of implementation. This grant also funds the Resettlement of Isle de Jean Charles, a low-lying coastal community at the nexus of migration and climate change.

The Resettlement of Isle de Jean Charles: "Not a Simplistic Move"

HUD awarded $48.3 million to the State of Louisiana's Office of Community Development to plan a scalable and economically viable community resettlement with former and current Isle de Jean Charles residents. Following decades of contending with the effects of land, community and livelihood losses, Island residents will be relocating largely together as a collective group in 2021-2022. For many, they are leaving the only home they have ever known. The Islands' residents are almost all indigenous and interrelated descendants of tribes seeking refuge from persecution more than a century ago. They have made the Island in Terrebonne Parish their home for multiple generations and embody a strong sense of place and attachment to it. An elder resident recalled that at "at one time, I couldn't see marshes on the other side because there were so many trees. People would use old time, home remedies." He pauses. "No more." (resident interview, August 17, 2012). Islanders could grow a majority of their food and had daily family visits. Imbued throughout their stories are feelings of unease for the future of the Island and distress of losing their home. Cognizance of the impending hazards and current risks presents challenges to emotional and social wellbeing (Fritze et al., 2008) and can cause feelings of displacement and solastalgia despite being in the same place one has lived for decades.

It is critical to recognize that the socially constructed vulnerabilities to frequent flooding and other coastal hazards are linked to colonial histories (Marino, 2012; Whyte, 2013). The processes of social and ecological marginalization play a significant role in the vulnerabilities to these risks for former and current residents (Jessee, 2020). In order to avoid replicating those inequities when it comes to the adverse effects of climate change, residents and the state are working together to facilitate a structured and voluntary retreat (Office of Community Development, State of Louisiana, 2019). The ultimate outcome of this process and the degree to which it is equitable remains to be seen and may take years, even a generation or two, to establish.[2].

During the ruthless hurricane season of 2020, nearly all Island residents evacuated seven different times, with Hurricane Zeta bringing 100 MPH winds on October 4 and wreaking havoc on Island homes. In 2019, Hurricane Barry brought eight feet of water onto the Island and Coast Guard helicopters rescued residents and a dog who had not evacuated. Residents on the protected side of the Morganza Hurricane Protection System did not see flooding as high as the Island. As one resident says, "climate change for me is the title for land loss. My landscape has changed and because that landscape has changed, that's what brought me down to this decision (to relocate)" (informal conversation, May 14, 2020). As Islanders describe how there was once land as far as the eye could see and they were once surrounded by relatives on all sides, feelings of solastalgia are now an integral element of living where they do (Muller, 2020).

One Island resident, weighing the resettlement decision, identifies the complexities inherent in decision-making, explaining "in the process, you know, this is not a simplistic move. This is not just about getting grant money, and then

[2]For more on the Resettlement of Isle de Jean Charles

moving. So, in that process right there, I'm going through it, I'm going through a thinking process, too and I'm moving along with it. Now, I'm not so moved by what's going on around me on the outside; I'm moved by what's going on with me on the inside" (resident interview, February 27, 2018). Many Island residents are in the process of assessing and re-assessing their decision to move while navigating the inherent cultural, social, environmental, economic, institutional and political complexities. Despite the differing circumstances from other residents on the coast, the process still presents myriad challenges.

As of the time of this writing, the infrastructure of the resettlement site, which residents named "The New Isle," is under construction. Weather permitting, homes will be completed in 2021-2022. 38 of 42 remaining Island families have chosen to move off the Island — 37 will relocate to The New Isle in the northern part of Terrebonne Parish. One family will relocate apart from the community, but elsewhere outside of the Special Flood Hazard Area (SFHA).

By establishing a proactive climate-based relocation framework, the resettlement of Isle de Jean Charles can assist communities facing similar challenges (Davenport and Roberston, 2016). To date, there is not yet a U.S. government agency, official procedure or funding stream dedicated to confronting climate-linked community resettlements in the United States and it is hoped that this resettlement program can reveal the need for building these tools and frameworks (GAO-20–488, 2020).

CONCLUSION

Putting the voices of residents first, such as in this research, can serve as a conceptual tool for future environmental migration work. Many participants spoke of either themselves or others whose culture and livelihood is contingent on the health and vivacity of the surrounding land and water. Residents spoke of their abilities to adapt when talking about the adversities they encountered, while at the same time questioning how much adaptation their communities can endure before becoming maladaptive. A greater understanding of what people view as effective and feasible adaptation strategies for facing future climate changes can increase policy approaches and resources in the future. Illuminating local perspectives can highlight decisions that occur at the nexus of migration, climate change and solastalgia.

Decisions to migrate or not, if that is a choice, involve foregoing insurance, waiting for levee protection or marsh restoration completion, rebuilding the family home after a storm, and contending with distressing feelings arising from watching familiar places bleed into the unfamiliar and unrecognizable. The conclusions of migration for which residents must eventually arrive, whether to remain or go, are, for many, steeped in solastalgic understandings of their homes. For many there is a sense of hopelessness, a yearning for what once was, particularly for elder residents who expressed that so much of the landscape has changed for them.

The compounding changes taking place around them are affecting the residents themselves, and these are not discretely separate, but, rather, are interconnected processes. Many residents' experiences of living in a cherished place adversely affected by climate change is a key signifier of solastalgia. This empirically grounded research elucidates some of the ways in which residents evaluate the benefits and hazards of living where they do and how it relates to climate change, migration and their social and emotional wellbeing.

This research examined place-specific and culturally subjective relocation possibilities, yet, the experiential knowledge has the potential to inform policies and practices of climate-driven migratory decision-making on a broader scale. Asking questions of the social relations, the socio-economic conditions, cultural constraints or traditions, and the context in which these occur offers insight into the push and pull many residents feel in their decision-making processes. Many coastal residents are tied to the landscape by feelings of solastalgia and view relocation as the last option. This feeling, intimately tied to sense of place, follows the general trend of wanting to stay where one feels most at home, despite the dramatic socio-environmental changes or being "on the front lines of climate change." As we develop policies and practices to facilitate and support more formal processes of relocation, policy makers and planners need to account for and work toward a greater understanding of the complexity and salience of solastalgia.

DATA AVAILABILITY STATEMENT

The data is not publicly available because it contains information that could compromise research participant privacy/consent.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Louisiana State University—Institutional Review Board. The patients/participants provided their informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

The author confirms being the sole contributor of this work and has approved it for publication. The content is solely the responsibility of the author and does not necessarily reflect the official views of funders or author's employer.

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Human Adaptation to Coastal Hazards in Greater Bridgetown, Barbados

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As urban risks associated with a changing climate continue to intensify, it is increasingly important to broaden our understanding of climate vulnerabilities in coastal cities and human adaptation to climate-related hazards. Coastal cities in small island developing states in the Caribbean stand to be among the most climate-impacted. This paper explores vulnerability to coastal hazards (sea-level rise, storm surges and flooding) in Barbados' capital city and its urban corridor—Greater Bridgetown. Specifically, it is a qualitative survey of climate change vulnerabilities and human adaptation in the study domain that is underpinned by three research questions: 1) In what ways is Greater Bridgetown vulnerable to coastal hazards? 2) What are the human dimensions of this vulnerability? and 3) What are the associated human adaptations? We apply a four-component adaptive urban governance framework to explore the role of the city's historical development, urban morphology, national-level institutions and relevant government and other stakeholder initiatives in shaping, reducing and/or increasing vulnerability to coastal hazards. The paper relates primarily to the governance dimension of the risk reduction framework articulated by the Intergovernmental Panel on Climate Change. In totality, a case is presented that highlights Greater Bridgetown's capacity for coastal/urban resilience, but which cannot be maximized without institutional prioritization of vulnerability, increased stakeholder "buy-in" and participation, along with significant investment in adaptation and the protection of valuable coastal infrastructure. The findings are of relevance to human adaptation within coastal cities of small island developing states.

Keywords: Caribbean, city, human adaptation, global climate change, inundation, resilience

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INTRODUCTION

Climate change is expected to have a global impact, but it is well understood among climate change scientists that coastal cities in small island developing states (SIDS) in the Caribbean stand to be among the most climate-impacted in the world (Mycoo and Donovan, 2017). SIDS across the globe face several climate-related hazards that place their resources, populations and assets at serious risk (Robinson, 2017; Robinson, 2018; Hay et al., 2019). The level of exposure to climate hazards varies from territory to territory based on factors such as population distribution, island type, and topography, all of which provide a framework when considering vulnerability (Forbes et al., 2013). Several studies on the Caribbean confirm their settlements have been impacted by sea-level rise (SLR), heavy precipitation events, tropical cyclones, and storm surges, among other climate

risks (Nurse et al., 2014; Cashman and Nagdee, 2017; Mycoo and Donovan, 2017; Mycoo, 2018). At the century scale and if adaptation is not pursued, the vast majority of low-lying islands, coasts and communities will encounter substantial risk from coastal hazards regardless of their level of development (Oppenheimer et al., 2019). Oppenheimer et al. (2019), p. 48 indicated that "even a small increase in mean sea level can significantly augment the frequency and intensity of flooding. This is because SLR elevates the platform for storm surges, tides, and waves, and because there is a log-linear relationship between a flood's height and its occurrence interval." Other studies suggest that the impact of sea-level changes on the settlements and infrastructure of small islands is proportionately greater than larger landmasses in part because of longer coastlines per unit of land area (Nunn and Kumar, 2018). In SIDS, major settlements tend to be located on the coast making them more exposed and more sensitive to climate-related hazards. For example, capital cities in the insular Caribbean are located on the coast and the majority are port cities (Cashman and Nagdee, 2017). Apart from high urban densities, the level of urbanization is very high in coastal areas in the Caribbean given that the population is attracted to flat lands, which generally cost less to build on when compared with hilly areas (Mycoo and Donovan, 2017; Mycoo, 2018).

Climate change has increased the intensity and spatial patterns of coastal hazards faced by Caribbean cities such as Bridgetown (Barbados), Georgetown (Guyana), Port of Spain (Trinidad and Tobago), Kingston (Jamaica), and Castries (St. Lucia) (Mycoo, 2014; Mycoo, 2017; Mycoo and Donovan, 2017). These cities are all located on the coast and the coastal hazards experienced include SLR, heavy precipitation events, tropical cyclones, and storm surges, and flooding. Based on various SLR models, it is projected that almost all coastal infrastructure in the Caribbean, including port and harbor facilities, will experience inundation in the future (Nurse, 2015; Cashman and Nagdee, 2017; Nurse, 2017). Climate-driven impacts on island infrastructure have been experienced for some time and are likely to become more widespread and more economically challenging in the next few decades (Robinson, 2017; Monioudi et al., 2018). Coastal flooding where there is a high concentration of population, infrastructure and economic assets, in particular, presents individuals, households, communities, and policy- and decision-makers in the region with numerous challenges, including effectively adapting to its impacts.

A systematic review of climate adaptation actions across all SIDS by Robinson (2020a) concluded that climate change impacts and adaptation responses in Caribbean SIDS are understudied. This paper seeks to help close this research gap. It qualitatively surveys climate change vulnerabilities in Greater Bridgetown (Barbados' capital city and its urban corridor) in seeking to understand human adaptation to coastal hazards (SLR, storm surges and flooding) within a SIDS context. We see human adaptations as the adjustments of human systems in response to actual/expected climatic stimuli, or their effects or impacts, that moderate harm, or exploit beneficial opportunities associated with climate change (IPCC, 2014, p. 1758). Three research questions underpin our enquiry: 1) In what ways is Greater Bridgetown vulnerable to coastal hazards? 2) What are the human dimensions of this vulnerability? and 3) What are the associated human adaptations? A four-component adaptive urban governance framework is applied to explore the role of the city's historical development, urban morphology, national-level institutions and relevant government and other stakeholder initiatives in shaping, reducing and/or increasing vulnerability to coastal hazards. The remainder of the paper is divided into four main sections. In the first section, materials and methods used are presented. Within this, Barbados' geography and its vulnerability to coastal hazards are covered. The adaptive urban governance framework is described, as well as how data were collected and analyzed. The second section presents the results, following the application of the adaptive urban governance framework, and which are organized according to the framework's four components. In the third section, presents a discussion in view of the three research questions. The fourth and final section highlights the paper's major empirical insights, which are that 1) vulnerability to coastal hazards in an urban landscape is linked to the city's historical development (temporal scale), and to its urban morphology (spatial scale), 2) that this vulnerability is further linked to its governance, particularly the institutions, laws, policies and plans that are in force, 3) that this vulnerability is significantly reduced where there are synergies between formal and informal governance, and 4) socio-political engagement is an essential component of human system adaptation in an urban landscape. Based on these insights, this paper contributes to the discourse on global responses to climate change and helps highlight the relevance and urgency of human adaptation within coastal cities in SIDS.

MATERIALS AND METHODS

Barbados' Geography and Its Vulnerability to Coastal Hazards

Barbados is a small island in the Caribbean with a land mass of 430 km^2. It is one of the top 20 most densely populated countries in the world with an estimated 2020 population of 287,375 persons and a density of 668 persons per km^2 (see **Figure 1**). Topographically, it is a relatively flat island—the highest point is 334 m above sea-level at Mount Hillaby in the Scotland District—this makes its coastal zone vulnerable to SLR, storm surges and flooding. The projections of higher sea-levels and increased tropical storm activity are expected to increase storm surge frequency and intensity. The main impact of storm surge is flooding, and because of Barbados' generally low-lying topography, it has been estimated that storm surge flooding events could extend over 150–300 m inland (Nurse, 2011). Barbados experiences flooding during the rainy season (June-November) when heavy precipitation over a short period places pressure on drainage channel capacity to cope with rapid surface water runoff, but storm surges also contribute to flooding, though mainly in coastal areas. On November 29, 2016, for example, the island experienced severe flooding resulting from a combination of a trough system and the Inter Tropical Convergence

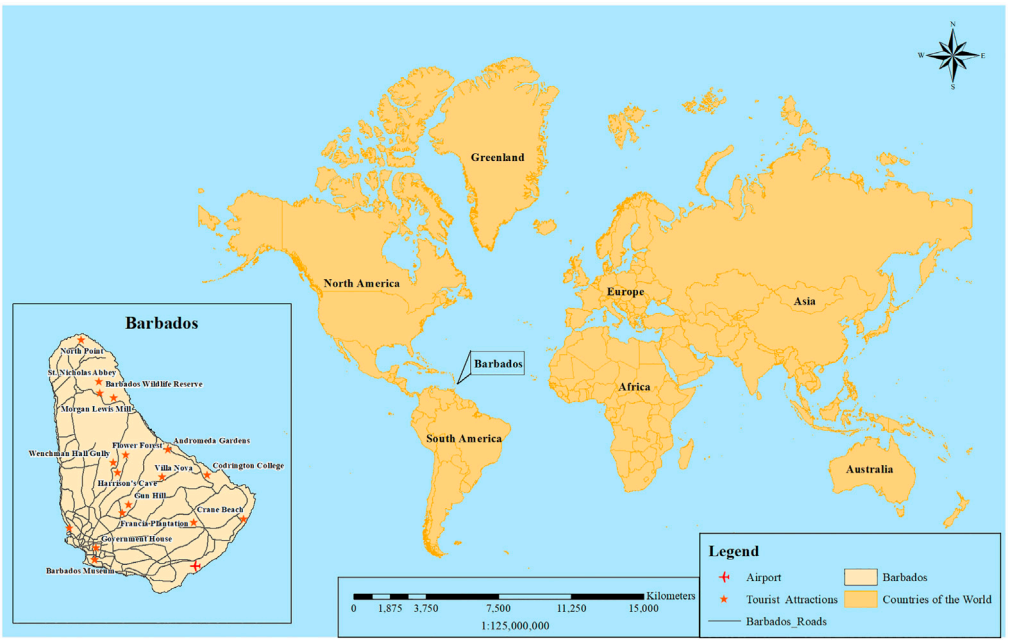

FIGURE 1 | Map of Barbados in relation to major geographical regions of the world (source: Rajesh Doodlal).

Zone, which generated intense showers lasting for just a few hours. The rapid onset and speed of travel of water from the central regions to the coast provided evidence of the vulnerability of infrastructure and settlements to the impacts of extreme events. There were several reports of property inundation and damage to vehicles where culverts were inadequate to channel this magnitude of storm water along regular courses to outfalls along the shoreline (Government of Barbados, 2018).

The majority of the country's population, coastal infrastructure and human settlements are located in the Low Elevation Coastal Zone (LECZ), which is the land area that is contiguous to the coastline up to a 10 m rise elevation. With rapid urbanization occurring within Barbados' LECZ, the country is especially vulnerable to SLR, storm surges and flooding. An estimated 18% of land mass in Barbados forms a part of the LECZ. Approximately 47,000 persons and 24% of human settlement occupies this zone (Columbia University, 2011). The concentration of socio-economic infrastructure within the LECZ multiplies the vulnerability of the economy to climate change and its impacts. Flooding, in particular, is a major risk for persons living in Barbados' coastal zone—it impacts the health and safety of the population, as well as the security of freshwater supplies (Cashman et al., 2010), buildings and infrastructure. Historical flood records reveal that social, protective and institutional facilities such as churches, cemeteries, government buildings, post offices, petroleum storage facilities, police stations and schools have all been damaged by flood waters. Infrastructure such as the Port of Bridgetown, bus terminals, and power stations are also affected annually by flood waters. Major transportation arteries, for example, Highway 1 and Highway 7, two of the island's coastal highways that run along the north and southeast urban corridor extending from Bridgetown, are located in the LECZ, and in several areas, are especially vulnerable to SLR, storm surges and flooding. **Figure 2** shows Holetown and Trent which are in the LECZ and climate change 25-year flood events and impacts based on various climate change scenarios.

With the impact from flooding and other natural and human factors, economic growth has been largely subdued over the last few years. In 2018, the Barbadian economy slipped into recession (Economic Commission for Latin America and the Caribbean (ECLAC, 2019). Nevertheless, tourism continues to be the economic mainstay, resulting in an increased dependency on a climate-sensitive sector. In 2018, this sector accounted for 22% of Barbados' gross domestic product (Government of Barbados, 2018). Tourism facilities such as hotels, guest houses, restaurants, bars and beachfront properties are located in areas prone to SLR, storm surges and flooding (Mycoo, 2006; Cashman et al., 2012; Mycoo and Chadwick, 2012; Scott et al., 2012; Mycoo, 2014). The hotels in Barbados, especially the larger ones, are on average located within the LECZ, which is consistent with the 1 in 100 inundation zones, placing them at risk of major structural damage associated with SLR, storm surges and flooding. Earlier studies reveal that approximately 90% of the island's hotels are located within 1 km of the high water mark and less than 20 m above sea-level (Belle and Bramwell, 2005; Dulal et al., 2009). Other studies, however, show that an estimated 50% of the hotel rooms in Barbados are at risk from a Category 3 hurricane because of their proximity to the mean sea-level. Becken and Hay (2008) estimate replacement costs of hotels could be up to US$550 million. Although its geographic location is an advantage in that it lies outside the Atlantic hurricane belt, the island does

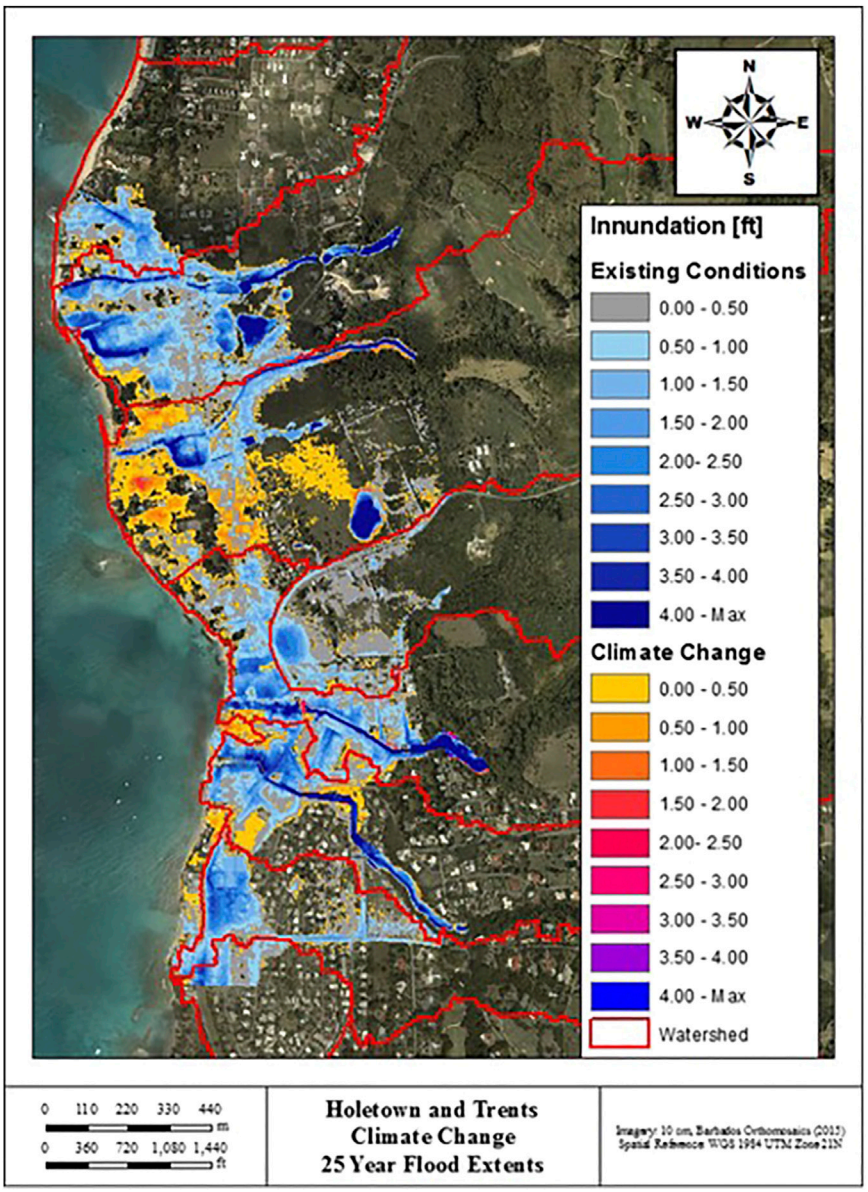

FIGURE 2 | Low Elevation Coastal Zone and Flooding in Holetown and Trent based on Climate Change Scenarios (source: Baird 2016).

not experience hurricanes as frequently as other Caribbean islands, but it is nevertheless exposed to major storms (Nguyen and Robinson, 2019).

Theorizing Vulnerability to Coastal Hazards in a Small Island Developing States Context

The demographic characteristics of Barbados are unique in contrast to other Caribbean islands in terms of population density, and the percentage of the population living in urban areas and along the coast. An estimated 44% of the population lives in urbanized areas, with the majority of persons settled in Bridgetown–a coastal city. The remaining population lives in other coastal areas, towns and villages, especially those located on the south and west coasts of the island (Government of Barbados, 2018). Currently, the majority of the population lives within three coastal parishes on the south-east, south and west coasts of the island which also support the four main urban centers—Bridgetown, Speightstown, Holetown and Oistins. Further, 25% of the population lives within 2 km of the coast in an "urban corridor," which runs along the entire length of the west and south coasts, and the parishes of St. Phillip, Christ Church, St. Michael, St. James, and the southern reaches of St. Peter. These areas constitute Greater Bridgetown (See **Figure 3**).

To understand Greater Bridgetown's vulnerability to coastal hazards (SLR, storm surges and flooding) and the associated human system adaptations, we apply an adaptive urban governance framework. Urban governance systems need to be

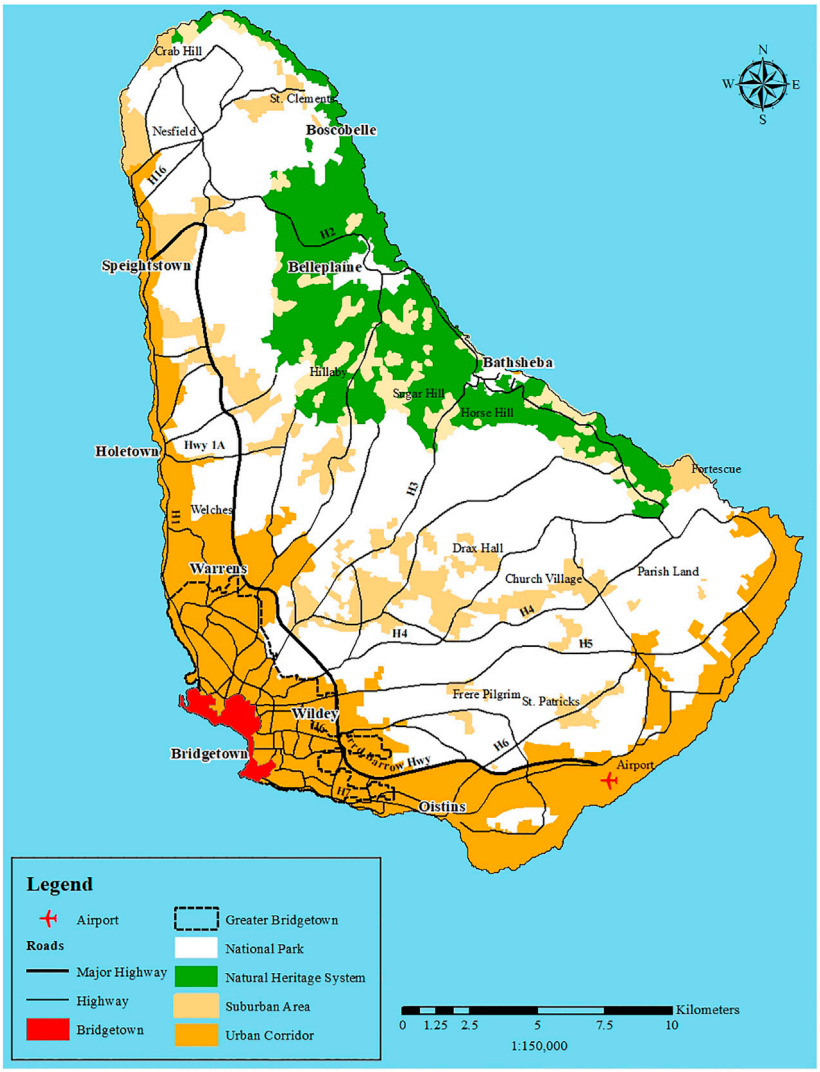

FIGURE 3 | Map showing the Four Main Urban Centers which constitute Greater Bridgetown (source: Rajesh Doodlal).

adaptive in order to deal with emerging uncertainties, dynamics, and pressures, including those related to climate change (Patterson and Huitema, 2019). Here, we understand "governance" as referring to the "institutional arrangements which shape actors' decisions and behavior, including the exercise of authority within groups or organizations" (Hatfield-Dodds et al., 2007, p. 4). Cities across the globe, as spatial groups, face multiple, interrelated and increasing climate change risks. In the Global South, including in the Caribbean, these risks arise within contexts that frequently involve substantial existing socio-economic inequalities and differential vulnerabilities (Bulkeley et al., 2014). Realizing adaptive urban governance systems requires that attention is paid to institutions, and in particular, processes of institutional innovation, if they exist. While scholars such as Patterson and Huitema (2019) develop multi-level heuristics to evaluate the role and effectiveness of institutions in urban adaptation governance, for example examining changes in institutional arrangements, rules-in-use and broader governance dilemmas, we reinterpret an earlier framework used in Birkmann et al. (2010). Our reinterpretation has four main components. Together, they offer an opportunity to conduct an in-depth analysis of urban adaptation processes, strategies and measures in Greater Bridgetown.

The application of the first component of our framework allows us to identify the "everyday" hazards in Greater Bridgetown through an interrogation of key threats, particularly in relation to the city's coastal assets. The second component explores the linkages between temporal and spatial scales, drawing attention to the historical, geographical and contemporary structural and non-structural adaptation processes, strategies and measures. This also enables us to comment on the robustness and flexibility of adjustments made in the human systems in response to actual/expected

climatic stimuli, or their effects or impacts, that moderate harm, or exploit beneficial opportunities associated with climate change. The third component identifies the synergies between formal and informal governance processes and strategies. It allows us to address their potential effectiveness and secondary consequences as well as flag areas of potential conflict that could inhibit adaptation progress. The fourth component assesses the integration of expert and local knowledge. In a cursory way, we also look at tipping points and whether the urban landscape can cope and adapt to stresses beyond certain thresholds. Our framework, though it modifies Birkmann et al. (2010), takes an integrative approach to studying the primary urban governance system in Barbados, with broader implications for other coastal cities in the Caribbean as well as other SIDS regions.

Data Collection and Analysis

Primary and secondary data were collected between September 2019 and July 2020. We used a directed approach to analyze the content of text and image data in order to derive historic and contemporary indicators of coastal hazard risks (SLR, storm surges and flooding) in Greater Bridgetown. Content analysis is a widely used qualitative research technique (Hsieh and Shannon, 2005). The directed approach is part of a naturalistic paradigm and is one of three distinct approaches to content analysis—it starts with a theory or relevant research findings as guidance for initial codes (Hsieh and Shannon, 2005). In our case, we were guided by the adaptive urban governance framework we described above and, therefore, focused on identifying 1) "Everyday" hazards associated with the city's coastal assets, 2) Trends in the city's historical development and urban morphology that shape its vulnerability, 3) Formal and informal institutions, policies and plans for managing climate risk and adaptations, and 4) The role of and the adaptation actions undertaken by experts in the central government vis-a-vis local residents. Text analysis drew from government documents and United Nations publications. Government documents included policies and plans related to physical planning, climate change, coastal zone management, sustainable land management, and urban heritage and conservation. United Nations publications focused on the economic impact of climate change on tourism and other sectors. We conducted a site visit in May 2020 to collect photographic evidence of the impacts of coastal hazards as well as human adaptations along the urban corridor. Some of the images produced by Barbados' government agencies were used to analyze flooding in Greater Bridgetown. By studying how Greater Bridgetown's coast is vulnerable to SLR, storm surges and flooding, this paper contributes to an understanding of the city's climate vulnerability. In applying an adaptive urban governance framework and selectively drawing on key coastal assets to illustrate examples, this paper helps assess the various dimensions of Greater Bridgetown's coastal vulnerability in order to identify how the city and its population can increase their resilience to immediate and future climate threats.

RESULTS

Framework Component 1: Acknowledging "Everyday" Hazards: Bridgetown and its Key Coastal Assets

Bridgetown is located in the urban parish of St. Michael on the southwest corner of Barbados. The city has 4.28 km of coastline and has several coastal assets, including the Bridgetown Deepwater Harbor, Careenage, Carlisle Bay, and the UNESCO World Heritage Site (See **Figure 4**). Built in 1961, the Deepwater Harbor is the Caribbean's most trafficked deepwater harbor. In 2018, the harbor facilitated 80% of Barbados' imports, 437 cruise ships, and approximately 830,000 cruise passengers (Hinkson, 2019). Located 1.75 km southwest of the Deepwater Harbor is the current Careenage—a commercial and recreational boat park, and iconic boardwalk that attracts locals and tourists (Google Earth, n.d.; Smith and Watson, 2008; Town and Country Development Planning Office (TCDPO), 2017). The city's main natural asset, Carlisle Bay, makes up nearly half of Bridgetown's total coastline and includes unique beaches and reefs (MPAtlas, n.d.). Tourism, residential, and government buildings line the Bay (Town and Country Development Planning Office, 2017a). Given the city's unique mix of old and new buildings, Historic Bridgetown, including its Garrison was declared a UNESCO World Heritage Site in 2011 (Government of Barbados, 2011). These four coastal assets are at risk of SLR, storm surges and flooding. The Bridgetown Deepwater Harbor and the Careenage are used to illustrate this point below.

The Bridgetown Deepwater Harbor represents the primary economic coastal asset of the city—it is most proficient for the transport of passengers from transnational cruise liners. The Harbor handles the most tourists per year in the Caribbean, supporting a vibrant tourism industry across Bridgetown (Government of Barbados, 2018). An assessment of the economic impact of climate change to Barbados' tourism industry found cruise ship facilities were damaged by [SLR], storm surge, coastal erosion and extreme weather events (Monioudi et al., 2018). These risks "will translate into costly [structural] repairs and potential loss of livelihoods. It was predicted that severe damage that requires such facilities to be completely closed will result in a decline in revenue from cruise tourism" (ECLAC, 2011). Increased average temperatures of 1.5°C will reduce the number of workable days for the Harbor along with other deepwater ports across the region (Monioudi et al., 2018). This assessment highlights an area of extreme concern regarding the accommodation and attraction of fewer tourists. Threats of coastal inundation from SLR, storm surges, flooding, and coastal erosion are obvious threats to the Harbor as it represents the intersection of a series of essential economic activities for the city of Bridgetown and its urban corridor.

The Careenage represents an area of high concentration of service infrastructure, including the Queen Elizabeth Hospital, the country's main hospital and two bus terminals. The local landmark and engineering antiquity are identified as an at-risk

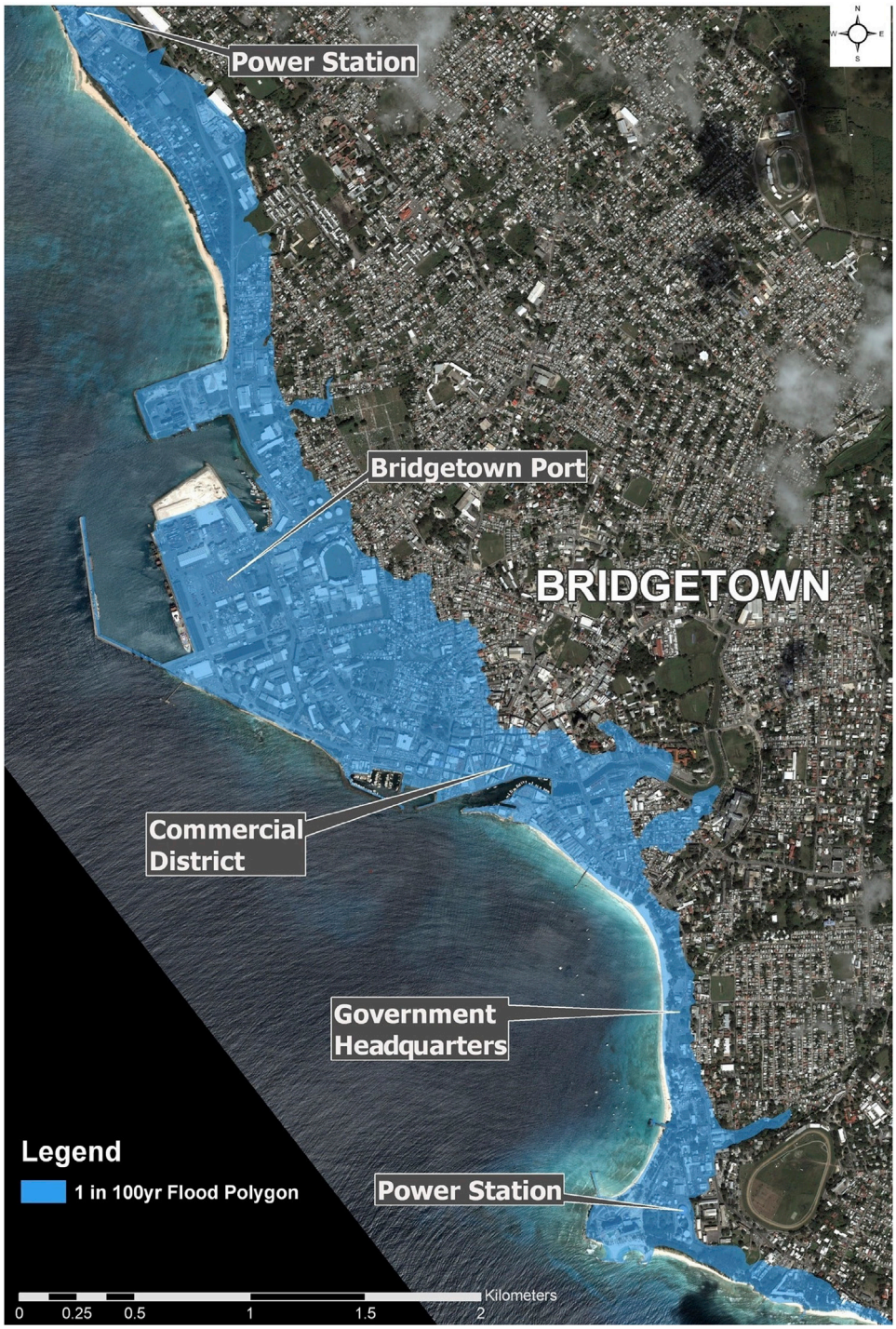

FIGURE 4 | Flood hazard map of Bridgetown showing some of the key coastal assets (Coastal Zone Management Unit, Government of Barbados).

coastal asset. The most direct impact of climate change on the Careenage and the downtown area is flooding (Government of Barbados, 2018). Inundation of this asset arising from SLR, storm surges, flooding, or extreme weather events has the potential to significantly disrupt economic and social activity. The lack of drainage infrastructure in the city, will intensify these issues , despite the city's Integrated Management Plan, which presents a case for "the redevelopment of the Constitution River for amenity and flood resilience purposes in the coastal floodplain of Bridgetown".

The results revealed the risk-focused decision by Bridgetown's institutions considers the future impacts, and the intensification

of climate change in the city. Flooding is an understood risk across these and other coastal assets. As a result of this, building institutional capacity to provide and maintain adaptive flooding infrastructure is crucial for the city.

Framework Component 2: Linking the Temporal and Spatial Scales: Historical Development and Urban Morphology

Historical Development

The land that Bridgetown is settled on was once a swamp, and prior to the arrival of British colonists, the area surrounding Carlisle Bay consisted of beach deposits and was covered with mangroves and other salt-tolerant trees and shrubs (Smith and Watson, 2008). Archaeological findings from the areas that are now Fontabelle, Spring Garden, and the Careenage indicate Amerindian settlement in and around Bridgetown dating back to 1623 BC. Amerindians in Bridgetown were subsistence farmers and fishers, utilizing slash and burn farming techniques that resulted in a landscape of small clearings of virgin forests, located close to the coastline. Archaeologists estimate that Amerindians numbered tens of thousands prior to the complete decimation of their population by 1,550 at the hands of Spanish colonizers.

Following the Spanish and Portuguese, who made stops on the island for water during the 16th Century, English ships landed in 1624, and Bridgetown was settled in 1628, which marked the beginning of a period of British colonization, spanning four centuries and most notable for its maritime development. Bridgetown's Careenage offered a safe, natural harbor for vessels and hosting dock facilities for shipbuilding and maintenance. Initially, society centered around small-scale cultivation of cotton and tobacco; rapid growth of Bridgetown and poor urban planning followed immediately. The streets were not planned on a grid system like those of the Spanish colonial towns, and a uniform organization style for the town that existed in other British settlements in the Americas was non-existent (Smith and Watson, 2008).

In 1640, the sugar trade was introduced to Bridgetown making it the center of international trade in the British Americas and one of its largest cities by the late 17th Century. The sugar trade brought even more rapid urban growth, and this, combined with Bridgetown's initial poor urban planning, resulted in limited sanitation, congested roads, disease, and fire. To address this, the Government introduced legislation to maintain public highways and formalized the city's boundaries in 1657 and 1660, respectively (Smith and Watson, 2008). However, fires continued to ensue. The most notable was the Fire of 1766, which damaged most of the town, and inspired the 1767 Rebuilding Act. The urban plan prepared following the Fire of 1766 greatly informed Bridgetown's present urban morphology—it catalyzed efforts to establish structural uniformity (Welch, 2004) and state control over urban development (Town and Country Development Planning Office, 2017a). From 1800 to 1885, Bridgetown served as the seat of government of the British colonies, and in 1881, the Barbados railway was completed from Bridgetown to Carrington, which contributed significantly to the continued development of the city (Town and Country Development Planning Office, 2017a).

In the early 20th Century, the arrival of the motor vehicle created issues for the narrow streets of Bridgetown. To address this, the Constitution River, Careenage, and remaining swamp areas were filled and then replaced by a channelized canal. This followed the construction of the Bridgetown Deepwater Port in 1961, which created a nexus for trade and communications away from the Careenage. With this construction came the conversion of vacant warehouses into offices, shops, and carparks, creating solid infrastructure for Bridgetown's emerging tourism industry. Barbados gained its independence in 1966, amid a period of high economic growth. Diversification of the economy from the 1950s into the 1970s brought increased settlement to Bridgetown so much so that by 1980, the population of Bridgetown represented almost half (43%) of the country's total (Town and Country Development Planning Office, 2017a). Additionally, a protracted era of colonial settlement and sugarcane cultivation led to the depletion of much of its forested area leaving the island with approximately 84 km^2 (19.5%) of forests. Mangrove loss persisted in the post-colonial period as building activity went ahead on the south and west coasts, and so the only significant remaining mangrove is the Graeme Hall Swamp, which stands on approximately 20 ha (Schueler, 2016).

These historical developments—the settling and filling up of swamplands, unplanned streets, construction of the Deepwater Harbor to facilitate trade and communications, expansion of the modes of transport (e.g., rail)—have all resulted in development in Bridgetown closely aligned to the coast and being highly concentrated in the coastal zone (Government of Barbados, 2018). These leave the city exposed to various coastal hazards, including SLR, storm surges and flooding.

Urban Morphology

Bridgetown's history greatly informs its contemporary urban morphology. In the northwest areas of the city, the urban and historical core combines institutional, residential, and commercial infrastructure, including key coastal assets such as Carlisle Bay and the UNESCO World Heritage Site (Town and Country Development Planning Office, 2017d). The Bay Street Corridor runs adjacent to Carlisle Bay and connects the urban core to southern parts of Bridgetown and the colonial Garrison, the other half of the UNESCO World Heritage Site. Much of the city's tourism infrastructure and government buildings are located along this corridor (Town and Country Development Planning Office, 2017c).

Presently, urban planning is primarily guided by the Town and Country Development Planning Office through the Physical Development Plans it produces (1976, 1991, 2003, 2017). These plans outline development visions for specific areas in Barbados, including Bridgetown and its urban corridor (Government of Barbados, 2008; Downes et al., 2015; Town and Country Development Planning Office, 2017a; TCDPO, 2017a; TCDPO, 2017b). In addition to the key coastal assets, other types of development in Bridgetown's coastal areas include residences and historic sites. While most Barbadians live in chattel homes (i.e., small moveable wooden houses set on

blocks or a groundsill rather than being anchored into the ground), which are typically occupied by lower-income residents, an increasing number are living in planned or multi-storey housing developments (Potter, 2000; McHardy and Donovan, 2016).

Bridgetown's early coastal location and urban morphology resulting from a concentration of population at the city center, and its major role as a port in the core-periphery relationship with England through which sugarcane exports were channelled, drew investments in infrastructure and buildings along the coastal city. This pattern was further entrenched in the postcolonial era when Government investments in offices, transportation upgrade and expansion, tourism and heritage and cultural buildings in the capital city increased, and later on extended to Greater Bridgetown. As a UNESCO World Heritage Site, Bridgetown blends historic and contemporary architecture. Given that the coastal zone is monopolized by the Heritage Site, which includes 30 distinct historic buildings or areas, the Government has increased efforts to redevelop and preserve these historic properties to enhance tourism and protect Barbadian heritage (Inniss, 2012; Downes et al., 2015; Town and Country Development Planning Office, 2017c). Such efforts increase the importance of protecting these areas from coastal hazards, including SLR, storm surges and flooding.

Framework Component 3: Identifying Synergies Between Formal and Informal Governance: From Institutions to Projects

Formal Governance: National-Level Institutions, Policies and Plans to Reduce Coastal Hazard Risk and Support Human Adaptation

Barbados' government is highly centralized. It has a long history of town and country planning, along with a series of national-level institutions, policies and plans that govern the urban landscape. In 1965, the Barbados Town and Country Development Planning Office (TCDPO) published the Town and Country Planning Act (CAP. 240), which has guided development plans for the entire island over the past fifty-five years and includes provisions on planning control and its enforcement. Since then, the Act has been amended multiple times and was recently replaced by the Planning and Development Act, 2019, that was passed in the Senate in January 2019. This Act created a new government department: The Planning and Development Department, which houses the Planning and Development Board, the body responsible for the implementation of the policies outlined in the Act. The Act has five purposes, which encompass the facilitation of land development, the establishment of standards for development, and the incorporation of public participation and easy access to information.

Besides the Town and Country Planning Act (CAP. 240), the TCDPO is also responsible for publishing Physical Development Plans (PDPs). PDPs provide a policy framework for development planning; there are four published PDPs. According to the Barbados National Communication to the United Nations Habitat III Report, the initial PDP was enacted in 1976. This was followed by the second PDP in 1991, a third plan in 2003, and the fourth in 2017. The concept of sustainable development emerged in the 1991 PDP, and governed the 2003 plan entirely (Downes et al., 2015). The PDP of 2017 seeks to address the critical impacts of climate change on Barbados by utilizing appropriate policies and strategies to enable its population to thrive and remain resilient in the face of climatic changes (Town and Country Development Planning Office, 2017a). The need for transformational and foundational change to urgently take action to deal with climate change is articulated in this plan (Town and Country Development Planning Office, 2017a). The 2017 PDP clearly states that one of its main principles is the adoption of adaptation approaches which reflect national and sectoral challenges due to climate variability and climate change. It recognizes existing developmental pressures resulting from demographic changes and investor demands are changing land use patterns, but envision that these must be addressed within the broader context of climate change and sustainable development.

The 2017 PDP recommends several measures to support human adaptation to various coastal hazards in planning decisions, which departs from the hard engineering measures usually employed to minimize such impacts. These risk-informed land use planning measures include the adoption of tree preservation and replacement plans for all development in the Integrated Coastal Zone Management areas; Enforcement of the Tree Preservation Act; tree preservation in Cultural Heritage Conservation Areas; increasing forest and ground cover through the policies of the Natural Heritage System to increase infiltration and rainfall retention in the watershed and to reduce run-off; and improving agricultural practices to reduce run off. The role of individuals and communities in adopting these adaptation options is seen as integral.

In 1985, the Town and Country Planning Act (CAP. 240) presented one early instance of potential climate change adaptation policy by establishing coastal setback lines for construction (Coastal Zone Management Unit (Coastal Zone Management Unit, 2020a). This represented institutional/human adaptation to changing coastal processes. Although the 1991 and 2003 PDPs prepared by the TCDPO introduced and emphasized sustainable development, more notable examples of institutionally promoted adaptation come from the Coastal Zone Management Unit which forms part of the Ministry of Health and Environment. The establishment of the CZMU is one of the earliest in the Caribbean region. The Unit released the Coastal Zone Management Act (1998), which called for a coastal zone management plan. The Integrated Coastal Zone Management Plan articulated comprehensive assessment, setting of objectives, planning and management of coastal systems and resources (Coastal Zone Management Unit, 2020a). The 1999 Integrated Coastal Management Plan for the West and South Coasts of Barbados highlighted the need to take into account global warming and its influence on sea level rise and increased storminess. It also advised that there was a need to distinguish between natural and human induced changes to ensure that policies were well-targeted to address their impacts (Coastal Zone Management Unit, 1999). The Integrated Coastal Zone

Management Plan also laid the groundwork for various CZMU initiatives like the Coastal Infrastructure Program (2002-2009) and the Coastal Risk Assessment and Management Program (2011-present). The most recently updated draft CZMU plan (2020b) noted that adaptive capacity for climate change adaptation remained weak (Coastal Zone Management Unit, 2020b) and called for strengthening this capacity through a coordinated governance arrangement.

The TCDPO and the CZMU, in an effort to support human adaptation to coastal hazards, has produced hazard and risk assessments and maps related to, among other factors, long-term SLR, storm surges, flooding from marine and terrestrial events, including cliff instability, and tsunami impacts. Additionally, they facilitate human adaptation by ensuring that coastal management and development control decisions explicitly involve consideration of policies and management guidance under the "ridge-to-reef" concept, and specifically, the principles and practice of Integrated Watershed Management Planning and the Natural Heritage System identified in the Integrated Coastal Zone Management Plan. As part of the human adaptation approach to coastal hazard risk reduction, communities are engaged in managing one of the last remaining coastal wetlands at Holetown Lagoon. All of these measures involve a high level of stakeholder input, which is consistent with the inclusiveness espoused in the United Nations Sustainable Development Goal 11 (Make cities and human settlements inclusive, safe, resilient and sustainable).

A key government policy is (re)locating inland from the coast—this has been a form of human adaptation to both coastal erosion and flooding, which has been in practice over several decades. Barbados has a national statute, which predates climate change discussions, that established a minimum building setback for all new buildings along sandy coasts of 30 m from the mean high-water mark. Along cliffs, the setback is 10 m from the under portion of the cliff. For Barbados, one objective is to ensure that built developments are located away from the zone of risk where SLR, storm surges and flooding occur (Mycoo, 2006). Cognizant of the importance of knowledge awareness among individuals and communities in adapting to climate change, the TCDPO and the CZMU more recently have indicated that applications for major developments or change of land use within 30 m of the coast will be subject to an Environmental and Social Impact Assessment and other supporting or technical studies, subject to the satisfaction of the Chief Town Planner or his/her designate (Town and Country Development Planning Office, 2017a). In considering such applications, the TCDPO will act on advice provided by the CZMU and the Ministry of Public Works. It may also impose conditions of approval such as maintenance requirements. Here, stakeholder input will be a key feature of policy- and decision-making.

The current TCDPO PDP (Town and Country Development Planning Office, 2017b, p. 57) provided detailed guidelines for individuals, communities and investors to safeguard their assets from coastal hazard impacts. All development applicants within Flood Susceptible Areas will prepare, to the satisfaction of the Ministry responsible for drainage, a hydrologic design study as part of the supporting documentation for development proposals. The purpose of this design study will be to assess the suitability of the development proposal to withstand projected flooding events on the site and to propose flood-proofing measures (Town and Country Development Planning Office, 2017b). Within Engineered Floodline Areas, new developments will not be permitted unless they can demonstrate that potential flooding can be contained using proposed flood proofing measures. Within Observed Flooded Areas, new developments will also not be permitted unless the stormwater management deficiencies within the area have been corrected to the satisfaction of the Ministry responsible for drainage, the Environmental Protection Department and Ministry of Health (Town and Country Development Planning Office, 2017a). In 100-year Floodline Areas, any new development or redevelopment areas will be designed with appropriate flood protection measures such as minimum freeboard elevation and prescribed limits to habitable space of building elements above flood levels (Town and Country Development Planning Office, 2017a). Development applications within the 100-years Floodline Area will be reviewed by the TCDPO based on the risk level and to determine whether an environmental and social impact assessment will be required. As part of the assessment, the applicant may be required to prepare and submit vulnerability assessments that explicitly identify the potential risks and mitigation measures acceptable to the Chief Town Planner. The environmental and social impact assessment process will take into consideration the impact of climate change and climate variability on the proposed development, and the development's influence on ecosystem processes and provisioning services (Town and Country Development Planning Office, 2017a).

Although there appears to be a sufficient amount of institutional interaction with respect to urban planning and some interaction with human adaptation, there remain some tensions and gaps between these institutions and their policies, most of which are highlighted in the TCDPO's Draft Green Paper on Planning Law Reform. First, it finds that there are issues surrounding the legal status of PDPs. Second, the Draft Green Paper calls for more clarity on the ways in which the Coastal Zone Management Act and the Town and Country Planning Act should interact and the role of the CZMU in decision-making on planning applications (Town and Country Development Planning Office, 2017a). Such tensions have particular significance to the coastal assets that are referenced in this paper because each asset falls within the coastal zone and, therefore, could be managed in accordance with both the Coastal Zone Management Act and the Town and Country Planning Act, potentially resulting in a mismanagement of development, and increased vulnerability because of overlapping jurisdictions. Third, the Draft Green Paper highlights a need for stronger provisions relating to the built heritage of Bridgetown, which is most likely a reference to Bridgetown's status as a UNESCO World Heritage Site (Town and Country Development Planning Office, 2017a). This holds particular relevance to the UNESCO World Heritage Site, since inadequate regulation of development in or around this asset could significantly increase its vulnerability to climate change.

TABLE 1 | A Summary of Bridgetown-specific initiatives.

Adaptation Initiative	Climate risk addressed	Stakeholder	Adaptation Typology	Coastal Asset
Constitution River Project Phase III- Flood Mitigation Works (2015) (Bahamas Trade Info, 2017; Nation News, 2015)	Flooding	Caribbean Development Bank (CDB), Barbados Tourism Investment, Inc. (BTI)	Implementation/Management	n/a
Coastal engineering infrastructure, including revetments and sea walls (1995, 2014) (Coastal Zone Management Unit, 1998; Government of Barbados, 2011; Flour Mill, St. Michael, Barbados, n.d; Thompson, 2013)	Coastal erosion and inundation, sea-level rise, protection from extreme storm surges	Coastal Zone Management Unit (CZMU), Infra, Inc., Inter-American Development Bank (IDB)	Implementation/Management	Bridgetown Deepwater Harbour Historic Bridgetown and its Garrison
Historic Bridgetown and its Garrison: Action Plan for Risk Management (2011) (Government of Barbados, 2011)	Flooding, sea level rise, frequent and intense storms, high levels of rainfall	CZMU, Department of Emergency Management, Government of Barbados	Implementation/Management	Historic Bridgetown and its Garrison
Aquarius Watersports Summer Camp (2005-2006 and 2018) (ICRI, 2018; SGP The GEF Small Grants Programme, n.d)	Marine ecosystem loss and damage	Barbados Marine Trust, International Coral Reef Initiative, Small Grants Programme through the Global Environment Facility	Education and Knowledge Management	Carlisle Bay
Caribbean Youth Environment Network Barbados (CYEN) (1993-present); Barbados Today, 2019)	Marine ecosystem loss and damage	CYEN, Ocean Conservancy	Education and Knowledge Management	Carlisle Bay
Carlisle Bay Marine Park (1997-2003) (CZMU, n.d. (b); MPAtlas, n.d; UN ECLAC, 2011	Erosion, marine ecosystem damage from pollution	CZMU	Implementation/Management	Carlisle Bay

Formal Governance: Programmes and Projects to Reduce Coastal Hazards and Support Human Adaptation

Flooding due to storm surges has had a large influence on residential, commercial and tourism assets, with estimated damages in the range of approximately US$1.5 billion for the 100-years condition (Coastal Zone Management Unit, 2020a). Some of the greatest damage has been in the Bridgetown area, yet most efforts to address coastal vulnerability to climate change in Barbados occur outside of Bridgetown. For instance, in the late 1990s to early 2000s, Barbados built several structures, such as boardwalks or groynes, to reduce coastal erosion. However, these structures are primarily located north or southeast of Bridgetown in Holetown and Rockley Beach, respectively (Mycoo, 2014; Coastal Zone Management Unit, 2020a). Furthermore, the implications of national vulnerability initiatives for climate risk reduction in Bridgetown are unclear. As an example, the Coastal Conservation Feasibility and Pre-Investment Study (1991) and Coastal Risk Assessment and Management Program (2011-present), funded by the Inter-American Development Bank, evaluated and addressed coastal climate hazards to Barbados' south and west coast (Mycoo and Donovan, 2017). While Bridgetown is located on the southwest coast, it is unclear whether these initiatives identified climate vulnerabilities in or specific risk reduction actions for the city. Therefore, national efforts to address coastal climate risks lack specificity to coastal vulnerability in Bridgetown and its adjoining urban corridor.

Over the years, however, there have been programmes and projects aimed at reducing coastal hazards and providing support for human adaptation in Greater Bridgetown. In 2015, the Caribbean Development Bank provided a US$7 million loan to the Government to upgrade the Constitution River, the primary channel that drains Bridgetown. The project's objective was to reduce flooding in Bridgetown through drainage channel dredging and rock armouring (Caribbean Development Bank, 2015). The Government is currently executing the Water Resource Management and Flood Resilience Climate Change Program, funded with assistance from the United States Agency for International Development (Government of Barbados, 2018). Additionally, there are a few Bridgetown-specific vulnerability initiatives which address climate risk to the coastal assets we reference in this paper (See **Table 1**). These initiatives can be classified per Robinson's (2017, p. 681) adaptation typologies for SIDS, which were developed to categorize similar climate adaptations and assess adaptation trends across SIDS. The five typologies are: 1) observation and

assessments, 2) planning, institutions, and policies, 3) implementation and management, 4) monitoring and evaluation, and 5) education and knowledge management.

In Bridgetown proper and as indicated in **Table 1**, vulnerability initiatives (a) are mostly categorized under the "implementation and management" typology and (b) address flooding and marine ecosystem loss. Flooding and coastal inundation present the most direct climate risk to the city and its coastal assets, and as a result the Constitution River Project (2016) and coastal engineering infrastructure are important vulnerability reduction efforts (Government of Barbados, 2018). The Constitution River Project aims to reduce urban flood risk by creating better drainage systems. However, given the project is approximately 1 km inland, it is unclear how the upgrades address vulnerability to these coastal assets. Additionally, using funding from the Inter-American Development Bank and private donors, specifically from the Barbadian construction company Infra Inc., Bridgetown has built seawalls at the Garrison and revetments at the Harbor to reduce physical threats of coastal inundation and storm surges (Government of Barbados, 2011; Thompson, 2013).

While vulnerability measures classified as "implementation and management" actions are hard infrastructure projects aimed at reducing flood and coastal inundation risk, initiatives classified under "education and management" address social vulnerabilities to climate change. The Aquarius Watersports Camp and the Caribbean Youth Environment Network Barbados (CYEN Barbados) organize outdoor recreation experiences or beach clean-ups at Carlisle Bay, respectively, to increase youth capacity to respond to marine ecosystem degradation (Aquarius Watersports Barbados, n.d.; Hinkson, 2019; Caribbean Youth Environment Network in Barbados, n.d.; SGP The GEF Small Grants Program, n.d.). Overall, Bridgetown's limited number of city-specific initiatives address some physical and social vulnerability to coastal assets.

Although Bridgetown has had multiple PDPs with implications for climate vulnerability reduction, few plans have been implemented. For instance, Barbados participates in the Inter-American Development Bank's Emerging and Sustainable Cities Program, which supports Latin American and Caribbean cities in developing specific action plans to increase resilience (Inter-American Development Bank, n.d). Yet, it has not developed a Sustainable Cities Plan, the barriers to implementation are unclear, and the lack of follow-through on the Emerging and Sustainable Cities Program and other development plans is likely limiting the number and effectiveness of Bridgetown-specific climate initiatives. With these restrictions, the role of these initiatives in reducing coastal vulnerability is ambiguous. On the one hand, the Aquarius Watersports Camp inspired participants to think critically about or pursue marine environment conservation (SGP The GEF Small Grants Program, n.d.). This suggests that, along with processes to draft the Planning and Development Act and develop heritage-based tourism, climate resilience efforts could also be increasing community engagement in Bridgetown–a significant shift given the city's historic lack of public participation. On the other hand, existing Bridgetown-specific initiatives fail to address climate risks at the Careenage. Additionally, only half the initiatives address flooding or coastal inundation, the largest threats to key assets. Therefore, these gaps suggest that vulnerability reduction efforts in Bridgetown are disconnected from the city's major climate risks.

Informal Governance: Adapting Coastal Assets for Local Needs and Uses

Research by Jaja et al. (2017) shows that, given that potential climate impacts are experienced more locally, it is important to focus community-based or social adaptation responses to identify actual climate impacts. In Barbados' urban corridor community efforts, social adaptation responses point to the climate change impacts that the population is most affected by such as flooding, erosion and storms. Climate change and associated coastal hazards impacting Greater Bridgetown have led to human adaptation in several ways where locals are adapting coastal assets for their needs and uses. Losses to coastal ecosystem services, infrastructure damage and threats to livelihoods due to climate change have promoted human responses to improve economic resilience. The island's tourism product focused in the past on beach tourism and catered to mainly tourists from the United Kingdom, and to a lesser extent, the United States (Lorde et al., 2011). Nature-based tourism, especially exploiting its coastal assets, including the beaches and coral reefs, has remained vital to economic survival, but the population has diversified into cultural and heritage tourism as a means of adapting to the impacts of climate change and to remain competitive in an ever-changing international tourism market (Richardson-Ngwenya and Momsen, 2017). With SLR and beach erosion occurring on the southwest coast, the designation of Bridgetown as a UNESCO World Heritage Site is strategic in reducing its dependence on beach tourism while simultaneously ensuring the preservation of historic buildings.

Another aspect of resident-led human adaptation in the Barbados context is the use of cultural traditions such as fish fry events to develop alternative livelihoods (Leslie, 2010). Small fish fry vendors, who tend to be mainly women from the community of Oistins, have self-organized and set-up stalls on Friday nights further inland from the coast where tourists can enjoy the local cuisine and delicacies, purchase arts and craft and participate in Barbadian and Caribbean entertainment (Leslie, 2010). This location and product diversification help minimize the vulnerability of small business operators to the vicissitudes of climate change such as SLR, storm surge and flooding. The women use their social capital formed through links with tour operators and hotels to promote their small business operations, especially the fish fry stalls (Richardson-Ngwenya and Momsen, 2017).

Human adaptation is also demonstrated in the actions taken by Oistins' fishers who are faced with high socio-economic vulnerability (Leslie, 2010). Many of their boats are usually uninsured against hurricanes and storms and they generally lack savings to absorb the cost of boat repair or replacement (Leslie, 2010). In response to livelihood threats from such events, fishermen have joined up with the women fish fry vendors, restaurants and rum shops to get catch sold so as to generate

FIGURE 5 | A beach bar along Barbados' southwest coast.

income, but also to raise savings to provide relief during times of hardship as is often the case in the aftermath of such extreme events (McConney et al., 2012; Monnereau and Oxenford, 2017). This pattern of adaptation is consistent with the rest of the Caribbean where most small-scale fishers, especially the reef-associated shallow shelf fishers have one or more additional or alternate seasonal sources of income within the fisheries sector, or from other sectors, especially tourism and construction (see Gill et al., 2007; Mumby et al., 2014; Gill et al., 2019). For fishers, forming partnerships with the women fish fry vendors is a social safety net that provides access to income and livelihood opportunities when other sectors fail or are disrupted by extreme weather events (McConney et al., 2012).

Beach bars and restaurants situated along Barbados' southwest coast, which provide additional evidence of informal coastal asset adaptation, are impermanent structures that are built directly on the beachfront and are easily relocated if flooding from SLR becomes more severe (See **Figure 5**). Operators of these small businesses have adapted the structures along the lines of chattel houses (i.e. small moveable wooden houses set on blocks or a groundsill rather than being anchored into the ground) for which Barbados is well-known (Richardson-Ngwenya and Momsen, 2017). This allows the structures to be disassembled (along with the blocks) and moved from place to place. Although the beach bars and restaurants are permitted at the beachfront to promote livelihoods associated with coastal tourism, their flexible structure inadvertently enables small business operators to adapt to coastal flooding and erosion by moving to higher ground.

Framework Component 4: Integrating Expert and Local Knowledge: Transcending the Central Government and its Technocrats

As Barbados' government is highly centralized, most human adaptation to coastal and other hazards has been coordinated by the central government, particularly through the TCDPO and the CZMU, within which the role of individuals and communities in adopting various adaptation options is seen as integral. Two examples will be recounted here. First, the 2017 PDP, released by the TCDPO, recommends several measures to support human adaptation to SLR, storm surges and flooding in planning decisions, which departs from the hard engineering measures usually employed to minimize such impacts. These risk-informed land use planning measures include the adoption of tree preservation and replacement plans for all development in the Integrated Coastal Zone Management areas. Second, as mentioned earlier, the TCDPO and the CZMU have indicated that applications for major developments or change of land use within 30 m of the coast will be subject to an Environmental and Social Impact Assessment and other supporting or technical studies subject to the satisfaction of the Chief Town Planner or designate. These two examples underscore the centrality of the government and its technocrats in human adaptation to coastal hazards; they also signal a recognition of stakeholder input being a key feature of policy- and decision-making.

Much emphasis has been placed on top-down or planned human adaptation, which also has the tendency to undermine the capacity for organized responses that are catalytic in transforming societies from within. However, there is scope to transcend the central government and its technocrats, and increasingly integrate local communities and their knowledge into human adaptation. In fact, individuals, communities and private entrepreneurs are progressively more engaged in finding their own homegrown solutions in adapting to climate change impacts such as flooding. This is illustrated by the fish fry events and the temporary construction of beach bars and restaurants described above. Additionally, although Bridgetown has historically lacked socio-political engagement (Pelling, 2003; Pugh, 2006; Pugh, 2013), the tide may be turning. During the drafting of the 2019 Planning and Development Act, the Government placed an emphasis on public participation, and hosted a stakeholder

discussion in July 2018 for professionals involved in the planning process (Joy, 2018). While the discussion was live-broadcasted and it was requested that any public input be emailed or mailed, it is unclear whether there were forums or meetings where the public could discuss the Bill and be informed of it in person. It is clear that the Barbados Government is making attempts at increasing participation, but the absence of prominent city-level institutions could be hampering greater adaptation action (see Robinson, 2020b), as local institutions can be better informed by the public, and therefore minimize the risk of misaligned policy.

DISCUSSION

In this section, we discuss the above results in view of the paper's three research questions.

Research Question 1: In What Ways is Greater Bridgetown Vulnerable to Coastal Hazards?

We found that flooding in Barbados as a whole, and in Bridgetown specifically, is attributable to anthropogenic pressures such as built development arising from urbanization as well as rising sea-levels and storm surges resulting from climate change. A long history of colonial settlement and sugar cane cultivation resulted in substantial forest depletion leaving the island with approximately 84 km^2 (19.5%) of forested area. Bridgetown's early coastal location and urban morphology resulting from a concentration of population at the city center, and its major role as a port in the core-periphery relationship with England through which sugarcane exports were channelled, drew investments in infrastructure and buildings along the coast. This pattern was further entrenched in the postcolonial era when government investments in offices, transportation upgrade and expansion, tourism and heritage and cultural buildings increased in the capital city and later on, Greater Bridgetown. As noted earlier, in the post-colonial era, many mangrove forests have been cleared to accommodate development along the south and west coasts and the only significant remaining mangroves are the Graeme Hall Swamp, which stands on approximately 20 ha. Forests and mangrove denudation significantly contribute to the population's increasing vulnerability to coastal hazards as forests and mangroves provide ecosystem provisioning services such as flood mitigation. The population settled along coastal parts of Greater Bridgetown are vulnerable to flooding associated with heavy rainfall in the wet season, rising sea level and storm surges.

Studies conducted in 2015 showed that there were shifts in migration from Bridgetown to an urban corridor made up of suburban centers. This changing internal migration pattern may reduce the vulnerability of the population to coastal hazards. These studies found that despite some economic growth, Bridgetown is experiencing declining population density, and increasing poverty. In addition to high rates of vacant buildings in Bridgetown many residents were relocating to emerging suburban areas north or south of the city, like Holetown and Warrens (Downes et al., 2015; Seijas, 2015). Statistical evidence confirmed that from 2004 to 2016, population density fell from 330 persons to 260 persons per km^2. Additionally, in 2010, the population of Bridgetown was comparatively poorer than that of rural Barbados (Downes et al., 2015). These characteristics suggest that Barbadians are either abandoning Bridgetown for more desirable opportunities or quality of life in surrounding areas, or, as Downes et al. (2015) suggests, gentrification from coastal development is pushing some Barbadians out of the urban center. This is, in some respects, relieving human pressure on the coastal plain—it will also likely reduce human impacts should there be a major flooding event.

Hydrological studies confirm that flooding results from an interplay of time, location and space of climate change, climate variability, soil characteristics, vegetative cover, topography and land elevation. In SIDS, urbanization and development have given rise to new causes of flooding that magnify adverse societal effects. Traditionally, across the globe, engineering has been seen as a panacea for flood mitigation. Flood management has, until recently, emphasized investment and trust in constructed solutions that rely on structural robustness. As Cashman et al. (2012) p. 2 note, however:

> "This attitude has been changing, brought about by a number of factors including the apparent failure of hard engineering to prevent or at least contain flooding events. At the same time there has been a shift in public attitudes towards flood risks; no longer are they seen as acts of providence for which the government has only a minor responsibility. Increasingly, flooding is seen as the responsibility of the government to do something about. More and more communities that are at risk are demanding that they be protected. Meeting such expectations and demands while in theory would be technically feasible is in practice impossible given the financial resources that would be required. As a result, other approaches are being actively explored that accept and live with floods. . ..and seek to place an emphasis on building resilience amongst stakeholders as a coping strategy."

In Caribbean SIDS, including Barbados, while much emphasis has been placed on engineering solutions to climate change, there are examples of ecosystem based measures solutions that are being used by individuals, households and communities in response to climate change challenges. Nevertheless, extensive social networks, personal economic investments and political obstacles complicate effective human adaptation.

Research Question 2: What are the Human Dimensions of This Vulnerability?

Specifically, we found that the four coastal assets referenced in this paper—Bridgetown Deepwater Harbor, Careenage, Carlisle Bay, and the UNESCO World Heritage Site—are physically, economically, and socially vulnerable to various coastal

hazards, including SLR, storm surges and flooding. Physically, these assets are located within the 100-year flood area; therefore, coastal inundation could lead to significant loss and/or damage (Town and Country Development Planning Office, 2017a). Economic vulnerability is illustrated by climate threats to the Bridgetown Deepwater Harbor. Wholesale and retail trade and tourism account for 34% of Barbados' gross domestic product (Government of Barbados, 2018). Given that the Deepwater Harbor facilitates this robust trade and tourism economy, inundation or damage to the Harbor would hinder its ability to host cargo and cruise ships, thereby straining these vital sectors and Barbados' economy (Government of Barbados, 2018). Despite the extent of this climate risk, there is a mismatch with initiatives along with evidence to suggest that climate threats have not been a primary concern for Bridgetown-specific vulnerability reduction programmes. For example, the UNESCO World Heritage Site Action Plan for Risk Management intends to address climate-related flooding and storm surges through coordinated disaster responses (Government of Barbados, 2011). This suggests that disaster risk management is prioritized over reducing coastal climate hazards and risks, potentially weakening coastal climate responses in Bridgetown. However, the fact that climate is one of many considerations also suggests a holistic approach to climate vulnerability reduction in Bridgetown. Medina et al. (2019) note that future climate vulnerability strategies in Barbados should combine disaster risk management with long-term initiatives to strengthen coastal responses to climate change, further highlighting the strength of an integrated approach. However, given that 1) the Careenage remains uncovered by any initiatives specific to Bridgetown 2) major climate risks to the key assets (e.g., flooding and coastal inundation), are rarely first concerns of Bridgetown-specific initiatives, and 3) few climate resilience plans are implemented, serious challenges to reducing vulnerability remain. In summary, despite Bridgetown's efforts to reduce physical and social vulnerabilities to its coastal assets and surrounding areas, the failure by the government and stakeholders to address and prioritize the most significant climate threats and implement a wide variety of climate risk reduction or development programmes, has ultimately limited the city's ability to reduce coastal vulnerability to climate change and build coastal resilience. These institutional and social barriers highlight the human dimensions of vulnerability to climate change as people's lives, livelihoods and assets remain exposed to risks and are impacted by cascading climate change events such as flooding and storm surges.

Research Question 3: What are the Associated Human Adaptations?

We found that institutions in Bridgetown have traditionally been deployed to understand risks to people stemming from coastal hazards, especially flooding, and have been mandated to manage coastal development. Yet, a key finding is that the city's local institutions are weak and there is a divergence between the planning and implementation of risk-focused adaptations. Further, less emphasis has been placed on the adaptation to long-term risks for coastal assets and areas, and as a result, these assets and the people living on the coasts are quite vulnerable. The TCDPO and the CZMU represent two significant institutions that operate to manage risks regarding elements of the coastal assets discussed. In order for Bridgetown to transform alongside the pernicious risks of climate change, an institutional prioritization of adaptation and resilience building in both key coastal assets, and the institutions themselves is essential. Addressing coastal asset vulnerability will likely require improving or increasing levels of public participation. Pelling (2003) notes that poor public participation could result in misunderstanding or poor mismanagement of climate risks within coastal communities, thereby suggesting that Greater Bridgetown's characteristic lack of community engagement will likely create and/or increase social vulnerabilities. However, the current community engagement efforts through heritage preservation or heritage-based tourism development will likely help to alleviate climate vulnerability, especially to the key coastal assets. The city's focus on redeveloping historic sites will also likely increase the role of public participation in Bridgetown. For instance, in the UNESCO World Heritage Site's Management Plan, the "wider public" is listed as a stakeholder and several institutions, including the Barbados National Gallery and Barbados Museum and Historical Society, are tasked with gaining community "buy-in" for heritage preservation (Barbados World Heritage Committee, 2011, p. 47). Given the traditionally low socio-political involvement of Bridgetown's residents, helping to protect and enhance heritage sites could decrease previous ambivalence toward public engagement (Pelling, 2003; Inniss, 2012). Current community-based responses suggest human adaptation is prioritized according to the most critical climate hazard issues that impact on livelihoods. This is clearly illustrated in the building of mobile beach bars and the location of fish fry operations further inland from the coast, thereby protecting community investments, assets and livelihoods from flooding, erosion and storms.

Considering governmental and community-based responses, continuing to explore the role of public participation and human adaptations in the context of climate change in Greater Bridgetown will be important. The paper's finding that capacity for coastal/urban resilience cannot be maximized without institutional prioritization of vulnerability, increased stakeholder "buy-in" and participation, along with substantial investment in adaptation and the protection of valuable coastal infrastructure, also has relevance for SIDS besides Barbados as they undertake human adaptations to coastal hazards as part of a wider strategy to build coastal urban resilience.

CONCLUSION

This paper set out to understand Greater Bridgetown's vulnerability to coastal hazards (SLR, storm surges and flooding) and the associated human system adaptations. It raised three key research questions to achieve its objectives: 1) In what ways is Greater Bridgetown vulnerable to coastal

hazards? 2) What are the human dimensions of this vulnerability? and 3) What are the associated human adaptations?

We found that flooding in Barbados as a whole, and in Bridgetown specifically, is attributable to anthropogenic pressures such as built development arising from urbanization as well as rising sea-levels and storm surges resulting from climate change. A long history of colonial settlement and monocrop cultivation, namely that of sugarcane, resulted in substantial forest depletion. Bridgetown's early coastal location, urban morphology influenced by a concentration of population at the city center, and its major role as a port in the core-periphery relationship with England through which sugarcane exports were channelled, drew investments in infrastructure and buildings along the coast. The four coastal assets referenced in this paper–Bridgetown Deepwater Harbor, Careenage, Carlisle Bay, and the UNESCO World Heritage Site–are located within the 100-year flood area and are, therefore, physically, economically, and socially vulnerable to various coastal hazards, including SLR, storm surges and flooding. Coastal inundation could lead to significant loss and/or damage in the near future. We also found that institutions in Bridgetown have traditionally been deployed to understand risks to people stemming from coastal hazards, especially flooding, and have been mandated to manage coastal development. Yet, a key finding is that the city's local institutions are weak and there is a divergence between the planning and implementation of risk-focused adaptations.

In view of our findings, we are able to derive four key empirical insights: 1) vulnerability to coastal hazards in an urban landscape is linked to the city's historical development (temporal scale), and to its urban morphology (spatial scale), 2) that this vulnerability is further linked to its governance, particularly the institutions, laws, policies and plans that are in force, 3) that this vulnerability is significantly reduced where there are synergies between formal and informal governance, and 4) socio-political engagement is an essential component of human system adaptation in an urban landscape. Using the case of Greater Bridgetown, this paper helps demonstrate that it might not be likely for a city's capacity for coastal/urban resilience to be maximized without institutional prioritization of vulnerability, increased stakeholder "buy-in" and participation, along with significant investment in adaptation and the protection of valuable coastal infrastructure. Governance challenges in the urban space, though dynamic, can be addressed through integrating approaches to planning across temporal and spatial scales, increasing transparency, public participation and the application of conflict resolution practices, as well as robust decision-making that reflects the key tenets of good urban governance.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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Wetland Utilization and Adaptation Practice of a Coastal Megacity: A Case Study of Chongming Island, Shanghai, China

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Coastal urban areas are faced with risks induced by global warming and sea level rise, which puts pressure on regional sustainable development. In particular, land use adjustment is closely related to climate change for a coastal megacity. Coastal wetlands on the edge of the megacity represent a vulnerable ecosystem and a key area in terms of the resilient adaptation strategy. However, the interrelationship between the development of these wetlands and the megacity's adaptation practice has not been sufficiently analyzed. From a historical perspective, based on document synthesis and field investigation, we attempt in this study to reveal long-term land use stages and driving factors in association with urban marginal wetlands, with a special reference to eastern Chongming Island, Shanghai. On such a basis, the future adaptation strategy of the megacity is evaluated. The analytical results show that this island has witnessed three periods of time for wetland utilization: traditional land use for salt production, fishery and agriculture before 1950, industrialization with rapid reclamation during 1950–2001, and the land use pattern orientated toward wetland ecosystem protection after 2002. The driving forces include sediment budget on the coast, wetland morphodynamic processes, sea level rise, population growth, and resource management policy changes. Transformation occurred between the wetland utilization stages in response to the changes of these forces. Furthermore, facing future climate change, there are different options of adaptation, e.g., retreatment and adherence. It may not be suitable for coastal cities with a large population to take the first option. It will be suitable for coastal communities to adhere to the location, if solutions to the problems of flooding risk, coastal erosion, and the maintenance of coastal facilities can be found. For eastern Chongming wetlands, as a key experimental area for ecosystem-oriented development in Shanghai, the transformation from the reclamation-oriented utilization toward the protection of wetland ecosystems represents the first step toward the latter option. We suggest that the next steps would be to maintain the ecological niche of the wetlands, to create new approaches to coastal engineering with contributions from the ecosystem, and to provide better ecosystem services.

Keywords: coastal wetland, land use change, climatic adaptation, sea-dike system, Chongming Island, Shanghai

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INTRODUCTION

Twenty three of the top 30 global big cities are located in coastal areas (UNDESA, 2015). With increasing risks of climate change and sea level rise, coastal cities face an enhanced pressure for sustainable development (Nicholls, 1995; Hallegatte et al., 2013; Sterzel et al., 2020). Furthermore, the coastal lowlands associated with megacities such as Shanghai, Bangkok, and New York form the first line of defense against emergence risks (Hanson et al., 2011; Temmerman and Kirwan, 2015). This situation is most serious for the densely populated urbanized coasts of Asia (The World Bank, 2010). In addition, population and wealth concentration in coastal megacities has been trending upward. Hence, the value of the wetlands, in terms of their natural assets, is also enhanced. The ability to deal with these valuable assets in an appropriate manner is, therefore, a critical component of climate change adaptation.

Generally, a coastal wetland refers to the intertidal zone and the adjoining nearshore seabed, above the -6 m bathymetry. In addition to being a precious land resource, it also provides a crucial habitat for plants and animals, a breeding ground for marine fish, filtration for pollutants, a buffer against marine hazards, a tourist attraction, and materials for science education (Goodwin et al., 2001). At the same time, its ecosystems are vulnerable to sea-level rise (Kirwan and Megonigal, 2013), extreme storm surges (Temmerman et al., 2013), and modifications due to human activities (Lotze et al., 2006; Kirwan and Megonigal, 2013). In response to rapid economic development during the 20th century, the annual rate of wetland loss was 0.7–1.2%, implying a total loss of around 63% for all the coastal wetlands (Davidson et al., 2014). During this period of time, land use changes reclaimed or converted 25–50% of the world's coastal wetlands for agricultural purposes (Kirwan and Megonigal, 2013).

Land-use adjustment is an important aspect of climate change adaptation in the coastal zone (Hadley, 2009). The Global Wetland Outlook (Ramsar Convention on Wetlands, 2018) emphasized the importance of coordinating the relationship between coastal wetland utilization and protection. With drastic changes in land use associated with coastal wetlands, they have become a key region for the study of human adaptation and sustainable development (Blankespoor et al., 2014; IPCC, 2014; Schuerch et al., 2018).

Recently, such studies have focused on the wetland systems in the Mekong River delta, Vietnam (Nguyen et al., 2016, 2017; Binh et al., 2020), on the low-lying Jiangsu coast, China (Bao et al., 2019a; 2019b), and the Yangtze River delta (Ma et al., 2018). For the megacity of Shanghai, which is situated at the Yangtze River mouth, scholars have identified high flood risk in the near future as a key concern (Yin et al., 2020), and evaluated the functioning of the coastal wetlands in flood hazard mitigation (Du et al., 2020). However, the balance between coastal wetland utilization and climate change adaptation needs further consideration, as is particularly the case for China.

On the one hand, China has rich coastal wetland resources. In 2014, China's coastal wetlands still occupied an area of around 58,000 km^2, accounting for 10.9% of the total wetland area of the country (Jiang, 2015; Sun et al., 2015). Rapid industrialization and urbanization have encroached on these resources. As a result of the utilization, about half of China's coastal wetlands disappeared over the last 50 years (Guan et al., 2012; Larson, 2015). The consumption of the coastal wetlands in the last two decades caused significant ecological degradation (Lin and Yu, 2018). The situation is most serious for China's three major coastal city clusters of the Bohai Gulf in the north, the Yangtze River delta, and the Pearl River delta (Chen et al., 2017; Lin and Yu, 2018). In order to protect the coastal wetlands, the government now prohibits any new reclamation projects (The State Council, 2018).

In Shanghai, the coastal wetland is mainly concentrated in the Yangtze River estuary (Zhang et al., 2015). Since 1980, this region has been the leading area of China's economic development, resulting in considerable change to the natural wetland system (Ma et al., 2019; Zhang et al., 2020). The estuarine wetlands in eastern Chongming Island (**Figure 1**) have witnessed historical changes in land-use patterns. A long-term perspective is of great importance in providing guidelines for adaptation activities in coastal areas (Colten, 2019), therefore, we should learn lessons from past wetland utilization to identify improvements in future adaptations. Local history and geography influenced past adaptations and will continue to influence the future. This information may be important, too, for other coastal megacities with similar wetland conditions.

Thus, the purpose of this study is to reveal the historical wetland utilization, land-use pattern changes, and the driving factors for the region of eastern Chongming Island, Shanghai. Then, the driving forces will be analyzed to provide explanations of the development stages. This analysis will provide the basis for a discussion of future climate change adaptation to define the role played by the coastal wetland system.

THE STUDY AREA

The eastern part of Chongming Island, Shanghai, is in the Yangtze River estuary (**Figure 1**). It had a total area of 1,267 km^2 in the 1980s, with over 90% of its land at an elevation of 3.2–4.2 m (based on Wusong Datum, which is close to the low water on springs) (Zhou, 1989). Sediment discharged from the Yangtze catchment over the last 1,400 years formed this island. By the end of 2019, the total population was around 0.7 million (Chongming District Statistics Bureau, 2020). With a history of artificial cultivation for more than 1,300 years, the formation of Chongming Island benefited from sediment accumulation associated with the evolution of the Yangtze River estuary; modern Chongming Island results from the merging of several sand banks and estuarine shoals (Cao, 1930; Chen, 1957). A combination of intense river flow and tidal currents has shaped a number of sandbanks; and they migrated and merged during the 11-14th centuries (i.e., the Song and Yuan Dynasties). Since the mid-16th century (the middle of Ming Dynasty), the position of Chongming's main island gradually stabilized, with continuous expansions (Chen, 1957; Wei, 1983; Chu, 1987; Zhang, 2005). It is arguably the largest estuarine sedimentary island in the world.

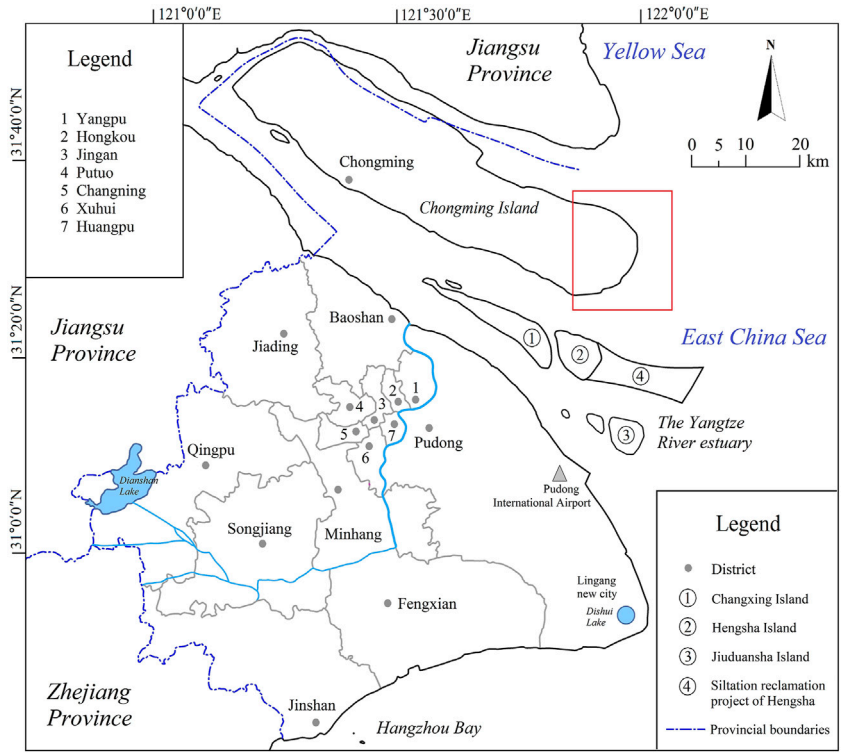

FIGURE 1 | The geographical location of eastern Chongming Island, Shanghai City.

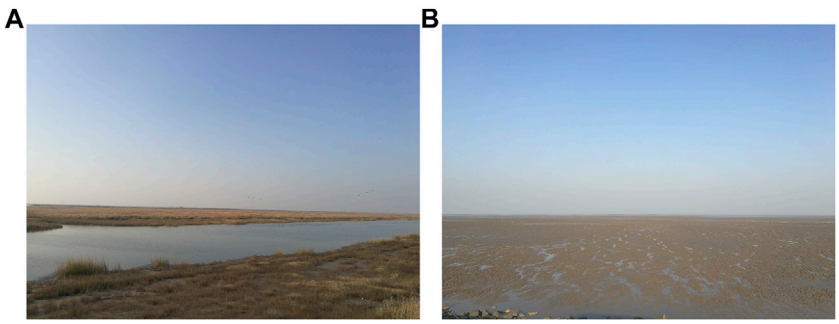

FIGURE 2 | The Dongtan wetland landscape of Chongming Island: **(A)** Artificial wetland inside the new sea dike built in 2015 (see the text for explanation); and **(B)** intertidal flat outside the new sea dike (natural wetland, including salt marsh and mudflat). Photographs taken by the authors, April 2018.

Eastern Chongming Island is a key coastal wetland in Shanghai, with around 682.4 km^2 in land area and an average elevation of l–2 m (Wusong Datum), which provides important ecosystem services (Zhou and Xie, 2012). The Dongtan Wetlands ("Dongtan" literally means the eastern tidal flat), with rich natural resources of tidal flats, benthic fauna and vegetation, became a key destination and stopover point for migratory birds in the Asia–Pacific region (Zhou and Xie 2012). Its distinctive geographical location and the habitat for birds earned it a listing as an internationally important wetland in 2002, then in 2005 it gained the designation as a national nature reserve (**Figure 1**; **Figure 2**).

The Chongming Dongtan Nature Reserve, located on the easternmost tip of Chongming Island, covers an area of 326 km^2. The average tidal range is 2.6 m, with a maximum tidal range of 4.6–6.0 m. Its area consists of two parts: 265 km^2 of the total area are outside of the sea dike, and the remainder are inside the dike. It is basically a tidal flat, with its internal areas consisting of salt marshes, mudflats, and silt-sand flats (Newton et al., 2020). The marsh plants include local species such as *Phragmites australis* and *Scirpus mariqueter* (Yan et al., 2007) and artificially introduced species *Spartina alterniflora* (Gao et al., 2014). The wetland serves as an important wintering and stopover site for 111 species of migratory waterbirds, together

with 94 species of brackish water, seawater, and migratory fish, accounting for over 80% of the total Yangtze estuarine fish species (The Management Office of Shanghai Chongming Dongtan Bird Nature Reserve, 2006).

MATERIALS AND METHODS

The datasets for this analysis derive from historical documents and published sources, together with field observations and remote sensing images (Google Earth). In China, official records preserved the evolution of coastal zone development and land use for any specific area over the last several hundreds of years. In this study, the records of the study area, from the 18–19th centuries, and the early 20th century were the primary sources. Since the end of the Qing Dynasty, the number of documentary records has increased.

In this region, salt production and subsequent agriculture represented major enterprise in early times. There are relevant documents (see Appendix Table A1), which contain historical information on wetland geomorphology, wetland vegetation distribution, sea dike construction, and traditional production activities associated with the tidal flat environments. We searched these historical documents and related data to identify the tidal flats area, the location of reclamation areas, and the positions of sea dikes and tidal mounds at different times. Then, we derived time-series changes from this data. During the Qing Dynasty, the government surveyed the tidal flats once every three years. Most of the data recounting those surveys were available in the Chronicles of Chongming County (Cao, 1930). It should be noted that *tide-mounds* represent a special artificial structure at that time. Salt production and agriculture concentrated on the upper parts of the tidal flat, i.e., the environment that was vulnerable to storm surges. In order to reduce storm surge damage, local residents built elevated platforms, consisting of piled tidal flat muds, known as *tide-mounds* near the production and living locations, so that the people were able to take refuge when a storm event occurred. Unfortunately, few records of the exact time of their building remain in the historical records. Nevertheless, this information is useful, together with the information on sea dikes, to demonstrate the scale and range of human activities. Furthermore, information on the utilization and the management policy for the wetlands, for early times, also existed in the records.

Recent publications and online data provided additional information on the coastal status of the 20th and early 21st centuries. They include the local chronicles of Chongming Island, land-use plans, and comprehensive investigation reports, e.g., *Comprehensive Survey Report on Coastal Zones and Tideland Resources of Shanghai* (Chen, 1988), *Chronicles of Chongming County* (Zhou, 1989; Zhang and Zhu, 2013), *Chongming Yearbook* (published by Chongming County Statistics Bureau during 1989–2019, see Appendix Table A2), the *Urban Master Planning of Shanghai (2017–2035)*, and *Statistical Yearbook of Shanghai* (Shanghai Statistics Bureau, 2019). These documents yielded information on the development status and social-economic data over the last few decades. Moreover, the photographs from field work and remote sensing images extracted from Google Earth also provided information on wetland landscape changes.

Globally, coastal development and societal responses occurred in three stages, i.e., an early period with fisheries, sea salt production, and agriculture; the era of industrialization and urbanization; and the current ecosystem-oriented use management. However, the scale and timing associated with these stages are highly variable. This pattern is also true for the coastal wetlands of the eastern China region (Bao and Gao, 2020). Here we divided the periods of the coastal development of Chongming Island according to the "three-stage" framework. The shift from one dominant economic period to the next determined the local timing of each stage. Land reclamation was a major activity during the first two periods and, therefore, we combined the data on land reclamation and distribution with information on economic and social life (e.g., economic production, wetland management policy, and population change) to define the dividing points between the different stages.

RESULTS

Three Stages of Regional Development, With Different Land Uses

Until the 18th century, salt production was a major activity on the island (**Figure 3**). Then, because the shoreline prograded seaward, the accessibility of saline water necessary for the enterprise receded. At the same time, expanding amounts of land became available for agriculture. In response to this landscape change, agriculture came to dominate the study area. This situation basically continued into the mid-20th century, i.e., around 1950. Hence, according to our definition, before 1950 the first stage of coastal development characterized the study area.

The transition from the second to third stage occurred in 2002 when Dongtan received its formal designation as a nature reserve. Between 1950 and 2002, industrialization was a major goal of Shanghai and this required large land areas. To meet this demand, developers reclaimed about 35 km^2 of intertidal land annually, and Chongming contributed a large portion (Zhou, 1989; Zhang and Zhu, 2013). Agriculture and industrial development occupied the reclaimed lands. A number of factories together with harbors and ports transformed sections of the island (Zhang and Zhu, 2013). During this period, although shoreline accretion continued, the total area of natural wetlands declined. An exception was the Dongtan area, where the rate of shoreline advancement exceeded that of reclamation. As a result, a relatively large wetland persisted. The establishment of the Dongtan nature reserve marks the beginning of the third stage. Although some reclamation efforts continued after 2002, the purpose was no longer to obtain the land for agricultural or industrial uses. Rather, it followed an engineering scheme designed to stabilize the environment for migrating birds (Sun, 2020).

Generally, the study area has experienced three stages of the intertidal wetland uses: 1) early development that was dominated

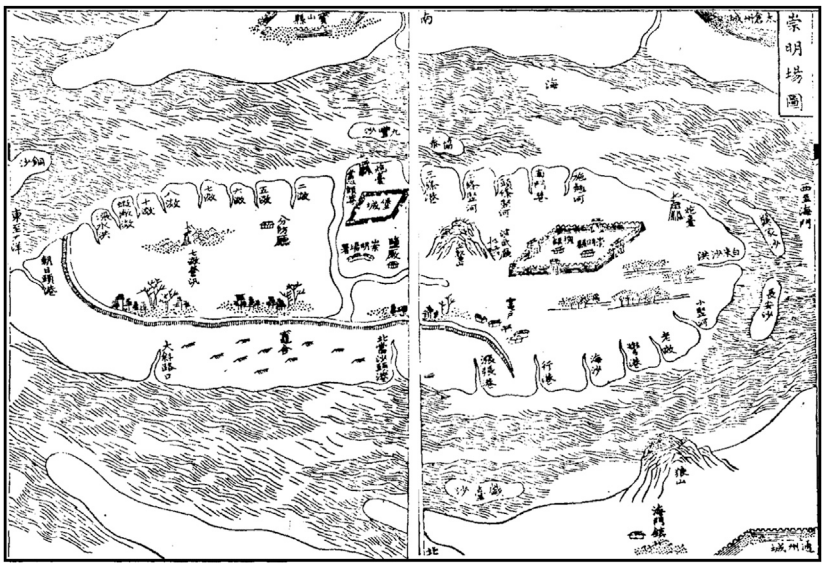

FIGURE 3 | Historical map showing the settings of Chongming Saltworks and the landscape of the Island. Note that this map is an overview picture of Chongming Island in the late 18th century, an original picture from Yan (1799), including information of saltworks, river, sea dike, county government setting, without latitude and longitude; north at the bottom and south at the top in this map.

by salt and agricultural production; 2) industrial development with rapid reclamation; and 3) conservation of the natural ecosystem, as represented by the nature preserve project. Each of the stages has its unique land use patterns (see below).

Traditional Development and Tidal Flat Conditions Before 1950

The wetlands in the study area maintained a natural landscape until the mid-20th century, with broad salt marshes and mudflats. In this environment, traditional livelihoods concentrated on sea salt production, farming, and fishing (**Figure 3**) (Zhu and Huang, 1688; Yan, 1799; Lin et al., 1881; Cao, 1930). These activities were vulnerable to river flooding and storm surges, before the mid-16th century due to the highly dynamic environment. For instance, in response to changing conditions, the Chongming County government changed its location five times (Zhang et al., 1604).

Subsequently, the main island gradually stabilized. During the years 1569–1574, local officials modified or built the main water channels in the island, including nine rivers and 33 branch canals to benefit soil desalination and agricultural development (Zhang et al., 1604). At the same time, continuous accretion of tidal flats caused difficulties for sea salt production. The saltworks had to migrate many times, and concentrated in the east of Chongming Island, providing access to seawater after the mid-18th century. During 1698–1826, three major migrations took place, each with a distance of 8–10 km; in 1869, the Qidong coast and Jiangsu Province became the destination of the last such migrations (Bao and Gao, 2020).

According to an inventory of land area of Chongming Island during Qing Dynasty, from 1730 to 1910, the tidal flat area in the island increased by 697 km^2 (Cao, 1930), with an annual growth rate of 3.9 km^2. After the mid-18th century, cotton plantations gradually replaced salt production (Bao and Gao, 2020). Since the early Qing Dynasty (i.e., the beginning of the 18th century), cotton fields expanded to occupy half of the total area of Chongming Island, as farmers continuously transformed the tidal flat wetlands into cotton fields (Zhang, 1727). In the mid-18th to the mid-19th centuries, the cotton planting area accounted for 60–70% of the total land area (Bao and Gao, 2020). In addition to salt-making and cotton farming, some fishermen collected shellfish or engaged in small-scale fishing over the shoals (Lin et al., 1881; Cao, 1930).

Sea dike construction and migration to the east in this region was an important part of the traditional development. There were two major old sea dikes: the first was built in 1593, and the second in 1762, some 2–3 km from the shoreline and 20–30 km seaward to the first one. Historical records identify it as the Zhaogong Dike (Bao and Gao, 2020). Further, residents built special life-saving facilities known as *tide-mounds* (Earth mounds, with a relative height of 2–4 m above ground) on the tidal flat. A total of 42 were built in 1732; they were maintained and rebuilt in 1751, along with nine more built on the newly formed high flat (Lin, et al., 1881). Generally, the *tide-mounds* occupied locations near the saltworkers settlements, providing emergency shelter when a storm surge came. Each of them could accommodate 100–300 people (Bao et al., 2020). Although the documents do not reveal the specific locations of the nine *tide-mounds* newly built in 1751, they likely stood near the 1762 sea dike (**Figure 4**).

In Chongming Island, according to the *tide-mound* distribution and shoreline changes, the outer boundary of traditional development activities mainly existing within the shoreline of the mid-18th century, terminating in the eastern

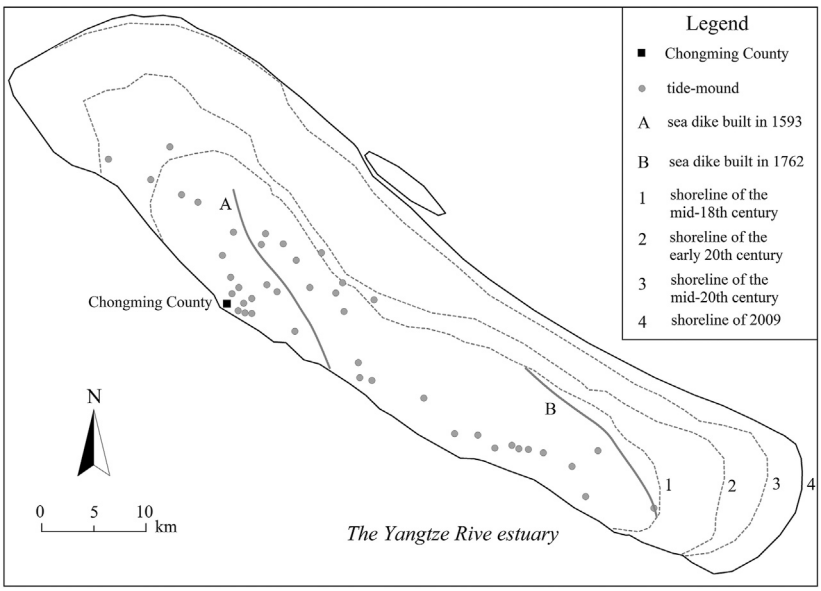

FIGURE 4 | Historical shoreline, sea dike and tide-mound changes of Chongming Island. The distribution changes of *tide-mounds* and sea dikes were from the Chronicles of Chongming County (Zhu et al., 1688; Zhang et al., 1727; Zhao et al., 1760; Lin et al., 1881; Cao 1930, see Appendix). Data on shoreline changes were from the Chronicles of Chongming County (Cao 1930; Yun, 2010).

part of the island at the 1762 sea dike (**Figure 4**). Beyond this boundary, there was no reclamation until the mid-20th century. The seaward expansion of sea salt production and agricultural activities was slow: outside this sea dike, there were vast salt marshes and mudflats, scattered with some saltworks (**Figure 3**).

Tidal flat reclamation needed engineering technologies, which had not yet been introduced from the western countries. Thus, it was too costly to transform tidal flats into agricultural land. Before the 20th century, traditional means maintained coastal wetland development, i.e., the extent and scale of human modification was limited.

Industrialization and Rapid Modification to Natural Wetlands During 1950–2001

After the mid-20th century, especially following 1979, Shanghai's economy expanded rapidly, creating a large demand for land resources. To meet this need, officials reclaimed 1953 and 2005, 1,014 km^2 of land area from tidal flats (Yun, 2010). Chongming Island became a major reclamation region, accounting for 60% of Shanghai's reclaimed territory (**Figure 5**). At this stage, the most prominent feature of land-use was the rapid encroachment on natural tidal flats. Modern engineering technology enabled construction of high-standard sea dikes to generate additional land resources for the expansion of agricultural and industrial communities.

In Chongming, there have been several large-scale reclamation schemes since the mid-20th century (**Figure 5**). In 1950, the island had a total land area of around 600 km^2, but 60 years later it reached 1,267 km^2. This involved reclaiming more than 650 km^2. Likewise, land utilization changed. Before the 1970s, agriculture was the main activity, but after the 1970s, the main purpose for obtaining land was industrial development. The rapid reclamation of wetlands provided land space for the expansion of coastal farms, the construction of ports, and other industrial facilities. Transportation infrastructure directly promoted additional industrialization of the industrial structure. At the end of the 20th century, the proportion land dedicated to secondary industry in Chongming County reached 37% (Chongming Yearbook in 2000, see Appendix Table A2).

The Dongtan wetlands were one of the key reclamation areas (**Figures 6**, **7**). Chongming Dongtan experienced peak periods of reclamation from 1960 to 1970, and from 1990 to 2001; which included prominent large-scale reclamation events in 1992, 1998, and 2001. Additionally, there were nine large-scale engineering schemes for sea dike building (**Figure 6**). However, there were some changes in the functioning of the sea dikes. In the 1960s and 1970s, the sea dikes provided barriers that enabled reclamation. In the 1980s and 1990s, engineers designed them to accelerate sedimentation on the tidal flat. After the Dongtan wetlands became an internationally important wetland according to the Ramsar Convention, its main purpose was to prevent coastal erosion and enhance the stability of the wetland ecosystem.

At this stage, nevertheless, the rate of reclamation exceeded the rate of accretion; as a result, salt marshes were progressively shrinking, in response to repeated sea dike construction projects (**Figure 7**). In Dongtan, the natural wetland area decreased from 197 km^2 in 1987 to 47.7 km^2 in 2002, a reduction of 75.8% (Gao and Zhao, 2006). Meanwhile, the designed minimum elevation of reclamation continuously fell, from above 3 m in 1950 to lower than 1 m (Wusong Datum) in 2009 (**Figure 5**).

For the entire island, the wetland area declined from 1,686 km^2 in 1980 to 1,350 km^2 in 2018 (i.e., a decrease of 20%). The reduction occurred mainly between the sea dike of 2,000 and the −5 m bathymetry isoline. Because of the inherent

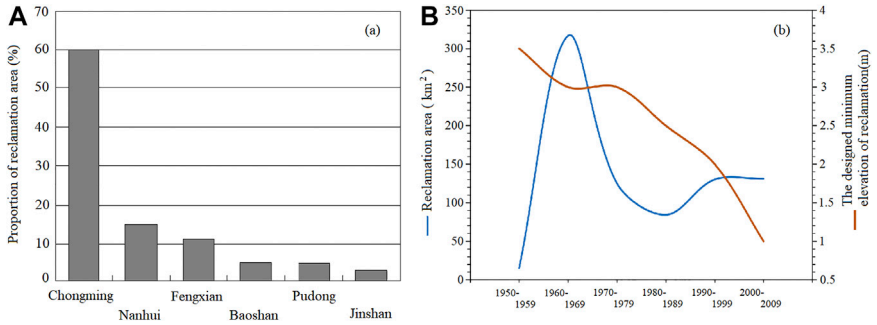

FIGURE 5 | Reclamation of Chongming Island after the mid-20th century. **(A)** Comparison of reclamation scale of the suburban counties of Shanghai during 1953–2004; **(B)** Historical changes of coastal wetland reclamation area changes and the designed minimum elevation of reclamation in Chongming Island. Data on reclamation were based on the Chronicles of Chongming County (Zhou, 1989), the Chronicles of Chongming County (Zhang and Zhu, 2013), and the Chongming Yearbook published by Chongming County Statistics Bureau during 1989–2010 (see Appendix Table A2). Nanhui District was officially incorporated into Pudong New District in 2009.

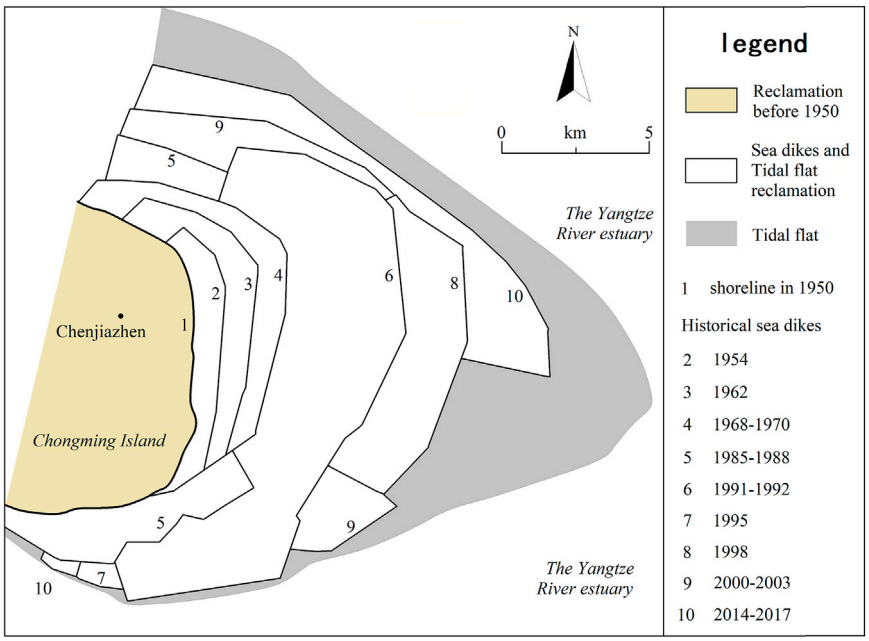

FIGURE 6 | Historical changes of sea dike and wetland reclamation in eastern Chongming Island. Data on shoreline and sea dike changes were based on Yun (2010), Yang et al. (2005), the Chronicles of Chongming County (Zhang and Zhu, 2013), the Chronicles of Chongming County (Zhou, 1989), and the Chongming Yearbook (Chongming District Statistics Bureau, 2020).

sedimentation laws associated with a tidal flat environment (Gao, 2014), the building of sea dikes can modify the cross-shore profile, i.e., increasing the temporal accretion rates the upper parts of the flat, which was observed a long time ago by Chen (1957).

Transformation Period for Land Use Pattern Since 2002

In the Urban Master Plan of Shanghai (1999-2020), issued by the Shanghai government in 1999 lists, Chongming Island as an important strategic reserve space for the city, but the important turning point was 2002 when Dongtan received designation as an internationally important wetland. The local government started to control the reclamation scale, but some engineering schemes continued with a new purpose to enhance the ecosystem services of the wetlands (Chongming District Statistics Bureau, 2020).

The government issued relevant policies, providing financial support to wetland protection, though it took a long period of time to make the necessary decisions. As early as 1992, officials discussed the feasibility of creating the Dongtan nature reserve. The Shanghai government officially approved the founding of the

FIGURE 7 | The satellite images of sea dikes and tidal flats reclamation in eastern Chongming Island. The red line represents the location of the sea-dike in 1762; the black line represents the shoreline in 1950; the white line represents old sea dikes; the yellow line represents new sea dikes in different periods; the broken blue line represents the boundary of salt marsh, and the broken white line represents the boundary of mudflat. Data on remote sensing image in four typical periods were excerpted from Google Earth; data on historical sea dikes and shoreline were excerpted from Yun (2010), Yang (2005), the Chronicles of Chongming County (Zhang and Zhu, 2013) and the Chronicles of Chongming County (Zhou, 1989).

"Shanghai Chongming Dongtan Bird Nature Reserve" in 1998. The Ramsar designation followed in 2002 and involved an area of 84 km^2 in 2002. Eventually, the State Council approved it to be a national nature reserve in 2005 (Ma and Ma, 2006; Xu, 2006).

Some relevant enterprises also played a role in the protection of Dongtan wetland resources. In May 2003, Shanghai Dongtan Wetland International Co., LTD. was incorporated, with a commitment to maintain the wetland services for the area between the sea dikes of 1992 and 1998 and to support migratory birds. The services include providing natural protection, scientific research and education, and ecological tourism and leisure resort.

The work plan of the Dongtan nature reserve shows that it will share 243.4 km^2, with the area of Chongming Dongtan Wetland of International Importance (which covers a total of 326 km^2) (**Figure 8**). Meanwhile, these designation restricted development within the area between the sea dikes built in 1968 and 1998. The area outside the sea dikes built in 1998–2001 became an ecological experimentation zone and a core region for the wetlands with salt marshes and mudflats (**Figure 8**). The most recent dike was completed between 2014 and 2017 to stabilize a part of the nature reserve as space for migrating birds. Thus, Dongtan has become a key experimental area for promoting coastal wetland ecosystem protection. By 2019, the wetland area for ecosystem protection according to local regulations reached 67.5% of the total of Chongming Island (Chongming District Statistics Bureau, 2020). In the Dongtan area 90% is dedicated to ecosystem protection. Furthermore, "green" engineering technology is reforming the existing sea dikes (Sha et al., 2008).

Overall, during the period from 2010 to 2020, the ecosystem-oriented construction improved the forest coverage rate, the quality of soil and air, the conditions of rural living and transport infrastructure, and promoted the development of the new industries, including flower gardens, the Dongtan Wetland Park, sports leisure and health activities, and other coastal tourism functions (Sun, 2020). These changes have brought more direct benefits to local peoples in term of employment and well-being. Now both the government and the local stakeholders believe that the maintenance of its natural environment and ecosystem services is vital to protecting the green space of Shanghai.

DISCUSSION: THE DRIVING FACTORS

Sediment Supply and Sea Level Rise

Sediment discharge from the Yangtze river is the controlling factor for the wetland accretion growth rate (He et al., 2010). However, the upstream dams and other human activities in the Yangtze catchment have caused a decrease in sediment supply which has allowed tidal flat erosion (Yang et al., 2005; Yang et al., 2011; Luo et al., 2015; Yao et al., 2017). The average sediment discharge during 1951–2000 was 425×10^6 t/yr (Wei et al., 2015), but fell sharply after 2000 to an average of 177×10^6 t/yr from 2001 to 2010 and 114×10^6 t/yr from 2011 to 2019 (Ministry of Water Resources, 2003–2019) (**Figure 9A**).

From 1762 to 1955, the rate of shoreline progradation, averaged 7 m/yr (Yang et al., 2001), but in the past 60 years it was around 200 m/yr, with an average annual growth rate of tidal flat area of 2.8 km^2/yr (Yao et al., 2017). Reclamation that caused readjustment of the cross-shore profile produced this change. Reclamation was most intensive during the 1990s, causing a shoreline advancement of 350 m/yr (Yao et al., 2017). However, as a result of the decline in sediment supply from the Yangtze River since 2000, the shoreline progradation rate declined to around 70 m/yr. On the upper parts of the tidal flat, the rate of accretion trended downward at Dongtan (**Figure 9B**). With reduced sediment supply from the river, the shallow water areas adjacent to the eastern island have experienced slight erosion during the last 40 years (**Figure 10**). During the years 1980–2004, the −5 m bathymetry isoline retreated toward the land, but it was generally stable from 2004 to 2018 (Yang et al., 2019). In the near future, sediment supply reduction will likely continue, which implies a reduced rate or termination of wetland growth (Yang et al., 2005; Li et al., 2006).

Further, the region is now influenced by sea-level rise. The rising water level and intensified storm erosion will impede wetland growth (Tian et al., 2010). According to the Ministry

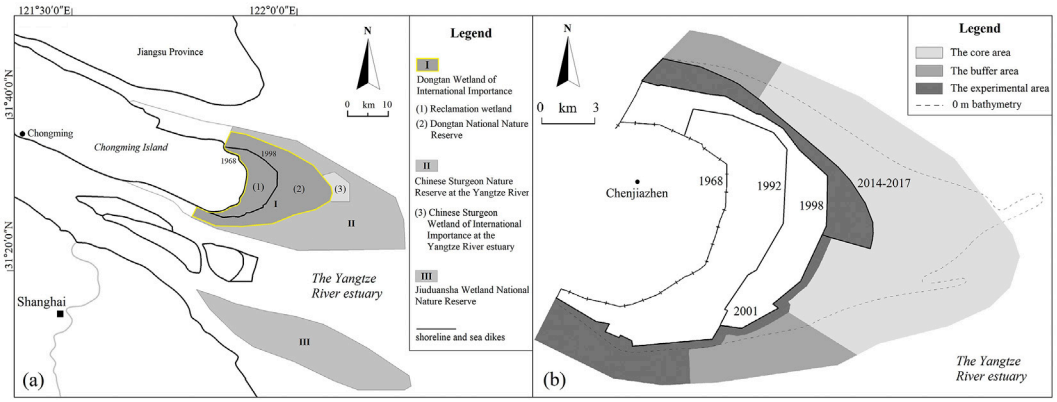

FIGURE 8 | Dongtan wetland conservation planning: **(A)** spatial distribution of the conservation projects; and **(B)** functional zone planning map of Dongtan National Nature Reserve. Compiled by the Kunming Survey and Design Institute of State Forestry Administration (2010).

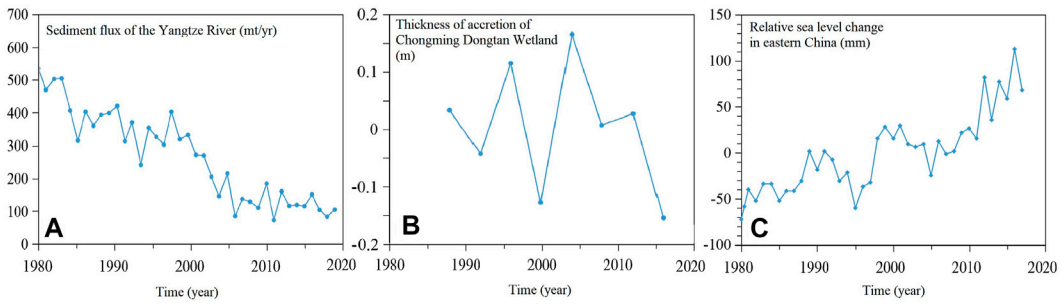

FIGURE 9 | The time-series of sea level, sediment flux and tidal flat accretion/erosion during 1980–2020: **(A)** sediment discharge from the Yangtze river in 1980–2002 (after Wei, 2015), and data in 2003–2019 were collected from Bulletin of China River Sediment (Ministry of Water Resources, 2003–2019, see Appendix Table A2); **(B)** sedimentation rates at the Dongtan wetlands (after He, 2020) and **(C)** local sea level curve (from Wang, 2018).

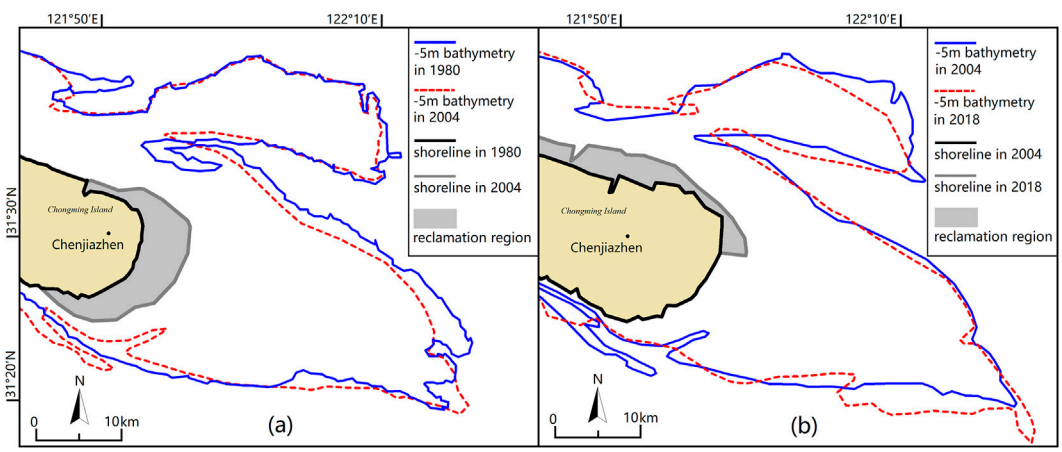

FIGURE 10 | The shallow water areas (within −5m bathymetry, Wusong Datum) during 1980–2018 (after Yang et al., 2019). Note that the shorelines of 2004–2018 were artificial (by reclamation).

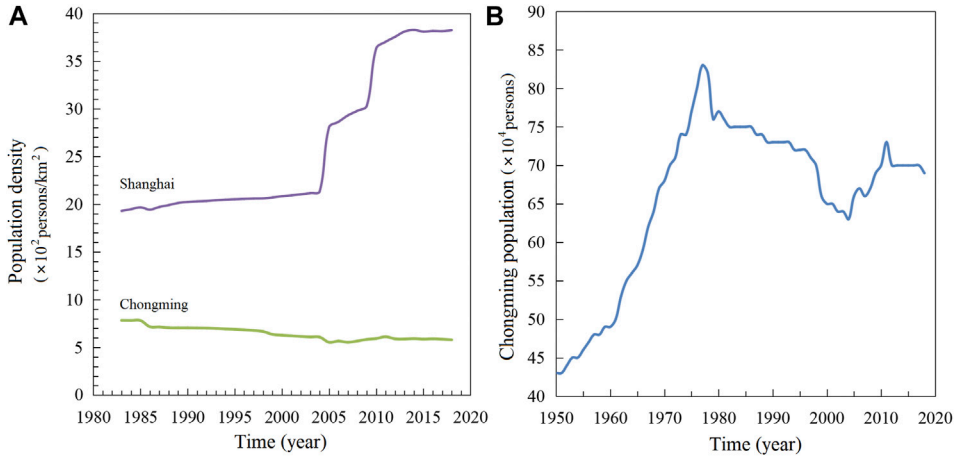

FIGURE 11 | Population changes of Shanghai and Chongming District: **(A)** population density changes during 1980–2018 (after Shanghai Statistics Bureau, 2019); and **(B)** population changes of Chongming District since 1950 (Zhou, 1989; Shanghai Statistics Bureau, 2019).

of Natural Resources (2020), from 1980 to 2019, the rate of sea-level rise along China's coastlines reached 3.4 mm/yr, which is higher than the global average (**Figure 9C**). Experts expect the sea level to rise another 51–179 mm in the next 30 years. Thus, the Dongtan wetlands will be at a high risk of being flooded and eroded (Yin et al., 2020). A representative scenario showed that flooding will threaten 64.1×10^3 km^2 in 2050 and 67.8×10^3 km^2 in 2080 of the Yangtze River delta, with an assumption of 3 mm/yr rise (Zuo et al., 2013). Likewise, inundation will impact around 40% of the land area of the Dongtan reserve by 2,100, based on a rate of rise of 0.88 m (Tian et al., 2010).

Hence, sediment supply and sea-level change are two of the key driving forces for wetland growth in the eastern Chongming area. In the past, the wetland growth may be divided into two periods: rapid expansion from the 1950s to the 1980s due to continued Yangtze river sediment discharge, and termination or erosion since the 1990s due to a combination of sediment supply reduction and sea level rise. For the future, the transformation from accretion to erosion and the likely intensification of erosion will cause problems to the Dongtan wetlands. Solutions must be sought to sustain or protect the wetlands, and should be incorporated in future land-use planning.

Population, Economic Growth, and Wetland Management Policy

As the largest city in China, Shanghai has a total land area of 6,340 km^2, but its rapid population growth creates challenges in terms of the human-land relationships (Wang and Yu, 2012). The GDP of Shanghai in 1980 was 31.2×10^9 RMB (i.e., 4.8×10^9 USD); it reached $3{,}268 \times 10^9$ RMB (i.e., 506.5×10^9 USD) in 2018 (Shanghai Statistics Bureau, 2019). Meanwhile, the total population of Shanghai increased from 11.04×10^6 people in 1978 to 24.24×10^6 by the end of 2018; the population density increased rapidly from 1,785 people in 1978 to 3,823 people per km^2 in 2018.

In comparison, the current population of Chongming is the lowest in Shanghai (**Figure 11**). Actually, after reaching a peak in the 1970s, the population has been declining for the last four decades, with a present population of 0.69×10^6 (**Figure 11**). The population density is also lowest in Shanghai, too, presently being 580 people per km^2 (**Figure 11**).

The land resources are so important for the continued development of Shanghai, and the existing coastal wetlands, with an area of 3.87×10^3 km^2 (Cai et al., 2014), are an important strategic space. However, cultivation of some of these wetlands depends on a government decision, which should be made on the basis of sound wetland management policies.

Presently, the wetland ecosystem services and the adaptation to future environment/sea-level change have become a priority in decision making. As far as the Chongming government is concerned, a Master Plan of Shanghai Chongming District Land Use (2017–2035), issued in 2018 (Chongming District Government, 2018), strengthens the policy of protecting the wetland ecosystems. The plan sets a limit of the population (i.e., a maximum of 0.7×10^6 people), prohibits further reclamation schemes, and reiterates that financial inputs will be guaranteed to maintaining the nature reserve. A program, known as "Eco-Chongming" seeks to manage the island in accordance with the plan (Sun, 2020). Its goal is to enhance the ecosystem services of the entire island, to improve the quality of urbanization, and to explore a new, ecosystem-oriented land-use pattern which will be resilient to environment/climate changes.

Hence, in addition to sediment supply and sea level rise, the population dynamics, economic growth, and wetland management policy are also the driving forces for the future of the Dongtan wetlands.

Options of Adaptation to Future Climate Changes

The third group of driving forces consists of the options for an appropriate adaptation to future climate change. On the one hand, before the end of the 20th century, the abundant sediment supply was beneficial to the wetland growth, which supported the

reclamation activity. On the other hand, the rising sea level and the sharp decrease of the river sediment supply will force the termination of reclamation, since tidal flats are no longer growing due to natural processes. Generally, at the long-term century temporal scale, sea-level change has an important impact, whilst at the recent ten-year scale, human reclamation had the greatest impact on wetlands, by influencing the river discharge and modifying the morphology of the intertidal zone. Until the end of the 20th century, there was a balance between the utilization of intertidal lands and wetland growth, but managing wetlands now depends upon the emerging patterns of climate change.

Sea level is not only rising, but the rise is also accelerating. At the same time, the intensity of storm surges will increase (Ministry of Natural Resources, 2020). One option to adapt to the marine change is to follow a managed realignment policy (e.g., Turner et al., 2007). This course, once made, would lead to the abandonment of some important coastal resources including infrastructures like harbors and sea dikes. Society would retreat to places with higher elevations. The coastal ecosystems, e.g., wetlands, will migrate landward: spaces will be arranged to accommodate these systems. Specifically, for our study area, the local government and stakeholders will have to give up their efforts to protect the Dongtan wetlands.

Indeed, the new set marine changes will have a huge impact on the safety of the coastal megacities, to say nothing of the associated wetlands. Beyond China, similar concerns exist. In Asia, the large-scaled, densely populated coastal cities such as Ho Chi Minh, Kolkata, Dhaka, and Manila face serious flood-related problems (The World Bank, 2010; Blankespoor et al., 2014).

In these regions, it is extremely difficult to adopt the managed realignment policy. China will have the highest population in its coastal lowland by 2060 (Hauer et al., 2020). If the people of Shanghai, for instance, will have to be resettled in inland regions, then the required space and material resources do not exist at the present time. As a result, the coastal communities will continue to run the coastal cities, at least for some prolonged period. In Shanghai, the "Urban Master Planning 2017–2035" (Shanghai municipality government, 2018) expresses the desire to do so. It has set a number of goals for future development, including the expansion of green space, the scale and spatial range of urban land uses, and the environmental protection criteria. In this conception, the coastal wetlands must be protected; the remaining question would be how to realize this ambitious goal (Schuerch, 2018).

What adaptation strategies are suitable for the local characteristics of Shanghai? Obviously the fate of the city will be linked with the fate of the coastal wetlands. Scientific research about the flooding risks and mitigation measures, prevention of coastal erosion, the maintenance of coastal facilities, as well as appropriate management and adaptation policies are essential. In addition, the experiences gained from historical development, together with the technology, e.g., the transformation of the land-uses to fit into the new tidal flat dynamic situations. Sustainability depends upon the solutions from this research and these experiences. Likewise, the sustainability of the coastal wetlands will depend on the suitability of the management policies (Woodruff, 2018).

For the Dongtan wetlands, the transformation from reclamation-oriented wetland utilization toward ecosystem protection represents the first step toward that "continuation" option. We suggest that the next steps would be to maintain the ecological niche of the wetlands, so that they can survive in even the severest environmental settings, to create new approaches to coastal engineering with contributions made by the ecosystem (i.e., "green") engineering schemes, and to foster better ecosystem services. The Dongtan wetlands have the potential to provide a pilot example for future adaptation. With the time window gained from this pilot project, the city would be in a good position to decide which option to adopt, to retreat or to resist (such as adherence/persistence adaptation).

CONCLUSION

(1) Eastern Chongming Island is a key area reflecting multiple long-term wetland utilization patterns in Shanghai. The related coastal development passed through three stages: traditional land use before 1950 as characterized by salt production, fishing and agriculture; industrialization with rapid land reclamation during 1950–2001; and the land-use pattern orientated toward wetland ecosystem protection after 2002.

(2) The timing and the scale of the different stages have been controlled by natural and human induced processes, including riverine sediment discharges, sea level changes, population and economic growth, and wetland management policy. During the first stage, the continuous sediment supply and wetland growth sustained regional development. However, during the second stage, the balance between the reclamation and wetland growth was broken due to the reduction of the sediment supply and sea-level rise, consequently development became unsustainable. The third stage is underway as and reflects a response to the demand of ecosystem services and the climate changes.

(3) The fate of the wetlands, like that of the city itself, depends on adaptation options for coping with future climate changes. For densely populated megacities, such as Shanghai, retreat may not be the best option. Rather, it will be suitable for the coastal communities to remain in place if planners, scientists, and policy makers can devise solutions, based on historical experiences, to the problems of flood risk, coastal erosion, and the maintenance of coastal facilities.

(4) Regarding the second option, i.e., adherence or persistence adaptation, as adopted by the Shanghai government in the Dongtan wetlands, it has a potential to provide a pilot example for future adaptation. For these wetlands, the transformation from the reclamation-oriented utilization to wetland ecosystem protection was the first step toward the adherence adaptation option. We suggest that the next steps should seek to maintain the wetlands' ecological niche, to create new approaches to coastal engineering with contributions from the ecosystem, and to provide better ecosystem services.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

BJ and GS conceived the research together. BJ collected materials and wrote the paper. BJ and GS revised the paper together.

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APPENDIX

TABLE A1 | The relative historical documents in wetland development data of the Chongming Island.

Title of documents	Editors	Year	Edition
Chronicles of Chongming county	Chen, W., et al.	1520	Old chronicles of Shanghai (volume of Chongming county). Shanghai ancient books press, Shanghai, 2011
New chronicles of Chongming county	Zhang, S	1604	Old chronicles of Shanghai (volume of Chongming county). Shanghai ancient books press, Shanghai, 2011
Chronicles of Chongming county	Zhu, Y., Xie, Y	1688	Collection of Chinese local chronicles, Shanghai chronicles (10), Shanghai bookstore press, 2010
Chronicles of Chongming county	Zhang, W	1727	Old chronicles of Shanghai (volume of Chongming county). Shanghai ancient books press, Shanghai, 2011
Chronicles of Chongming county	Zhao, T., et al.	1760	Old chronicles of Shanghai (volume of Chongming county). Shanghai ancient books press, Shanghai, 2011
Chronicle of liangzhe salt industry	Yan, F., et al.	1799	Zhejiang ancient books press, Hangzhou, 2012
Chronicles of Chongming county	Lin, D., et al.	1881	Old chronicles of Shanghai (volume of Chongming county). Shanghai ancient books press, Shanghai, 2011
Chronicles of Chongming county	Cao, B	1930	Collection of Chinese local chronicles, Shanghai chronicles (10), Shanghai bookstore press, 2010
Chronicles of Chongming county	Zhou, Z	1989	Shanghai people press, Shanghai

Historical reclamation and land use data before 1950 were mainly from the above historical local Chronicles; part data of historical reclamation and land use after 1950 were from the newly local Chronicles in 1989.

TABLE A2 | The main online data set related to Chongming Island, river sediment of Yangtze River and sea level of China.

Title of documents	Editors	Year	Links
Chongming yearbook	Chongming county statistics bureau	1989–2019	https://www.cnki.net/
Shanghai statistical yearbook	Shanghai statistics bureau	2019	http://tjj.sh.gov.cn/tjnj/
Chongming district statistical yearbook	Chongming district statistics bureau	2020	http://www.shcm.gov.cn/cmmh_web/html/shcm/shcm_qzfbmhxz_bm_qtjj_zwgk_tjgb/Info/Detail_1646111.htm
Bulletin of china river sediment (BCRS)	Ministry of water resources	2003–2019	http://www.mwr.gov.cn/sj/tjgb/zghlnsgb/
China sea level bulletin of 2019	Ministry of natural resources	2020	http://gi.mnr.gov.cn/202004/t20200430_2510978.html

These online documents provided part data about Chongming wetland development after 1950, and relative data of sediment deposition of Yangtze River, sea level change of China's East Sea, and population of Chongming Island and Shanghai City.

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Pipeline Logic and Culpability: Establishing a Continuum of Harm for Sacrifice Zones

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This article builds on the concept of Energy Sacrifice Zones, which has been used as a heuristic for areas negatively impacted by environmental degradation and/or pollution that harms nearby residents for broader economic gains elsewhere. Environmental justice scholars have since the 1980s identified urban "fence-line" communities as Sacrifice Zones, such as those along the industrialized Mississippi River corridor downstream of Baton Rouge, La., where public health and property values are impacted by plant emissions. More recent scholarship has identified analogous dispossession in coastal Louisiana, where indigenous and communities of color suffer environmental degradation and land loss from oil industry practices. Coastal oil and gas operations have left behind thousands of miles of pipelines, canals and subsiding oil fields that have accelerated marsh desiccation and land loss. This article argues that both inland and coastal areas of Louisiana are being sacrificed by the fossil fuel industry on a *continuum of harm* along pipelines from wellheads to inland plants. Oil wells, refineries, and petrochemical plants exist as nodes along a single line of production and manufactured demand for petroleum-based products, which also litter waterways and oceans. Such a continuum establishes a single Sacrifice Zone that conjoins multiple sites. Harmed communities need not be adjacent to one another to be considered logically contiguous and, therefore, subject to consideration of collective harm as long as they are linked by the material infrastructure that connects fossil fuel extraction, production and distribution. This zone of harm, once established, could be used to inform decision makers with more accurate and complex pictures of social and public health costs of industrial emissions and practices, particularly when considering proposals for plant expansions or new facilities. They may also be used to determine legal culpability in restitution claims by communities bearing the burden of the carbon economy.

Keywords: extraction, environmental justice (EJ), fossil fuels and carbon emissions, sacrifice zones, social justice

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INTRODUCTION: ECOLOGIES OF POWER

Due to the seminal work by environmental justice advocates Robert Bullard and Beverly Wright, the concept of the Sacrifice Zone has gained currency as a framing device for industrial sites situated in poor, often minority neighborhoods (1986). One of the most important indicators of an individual's health is one's ZIP code. Residents in areas that become Sacrifice Zones are disproportionately burdened with toxic chemical releases, presumably so that other Americans can benefit from low-cost goods produced by these plants. It is the intent of this article to extend the concept of Sacrifice

Zones geographically to connect non-contiguous areas that are impacted by a linked system of fossil fuel extraction and secondary industrial consumption. The article uses as a case study the south Louisiana region, which consists of a densely-clustered industrial river corridor, thousands of miles of pipeline infrastructure through coastal marshes, and intense land loss.

The article will demonstrate that disparate locations both offshore and inland are entrapped by a single system of fossil fuel extraction and production, and therefore, should be coupled together when designating areas as Sacrifice Zones. Such a framing device based on *pipeline culpability* may be used in a number of ways to articulate and quantify the collective harm done to communities who live in the destructive shadow of the fossil fuel industry. Coastal and inland fence-line communities may find mutual social and political solidarity to rebuff industry expansions and practices, which in the aggregate can be demonstrated to be more costly than representations by industry advocates about economic benefits and job opportunities that such facilities supposedly offer lower income communities. As global warming depresses the industry's image and bolsters more sustainable energy alternatives, the oil and gas industry is reportedly looking to shore up product demand through downstream, value-added production in petrochemicals (CIEL 2017). This directly affects Louisiana, where at least seven new petrochemical facilities and expansions have been approved here since 2015. Five more major projects are awaiting approval from the Louisiana Department of Environmental Quality, which has a reputation for rubber stamping industry actions (Together BR 2018).

The oil and gas and petrochemical industries have powerful actors in their corner to protect their interests. They are often awarded long term industrial tax breaks that starve local communities of important revenue sources for public services while forcing them to bear the burden of plant emissions (Staff Editorial, 2018, Staff Editorial, 2019, Staff Editorial, 2020; Together Baton Rouge 2018). Legislative bills are regularly introduced to shield industry operators from regulatory oversight and culpability. And the state's Department of Environmental Quality, charged with regulating one of the busiest clusters of industrial activity in the world, is perennially underfunded and reliant on 1990s technology, anarchic methodology and self-reporting by the plant operators themselves (Jacobs 2021). This leaves practical oversight to community members who document noxious smells and toxic releases through EPA-approved "grab air" bucket kits distributed by nonprofits, such as the Louisiana Bucket Brigade. Coastal communities, meanwhile, face their own industry threats from the labyrinth of aging pipeline infrastructure that crisscrosses coastal marshes and leads to massive land erosion and dispossession (Maldonado, 2018; Randolph 2018; Day et al., 2020).

But a renewed sense of energy has taken hold among impacted residents who are publicly and forcefully protesting plans by companies with powerful backers to build or expand operations that are supported by the state legislature, governor and local newspapers (Staff Editorial, 2019). A framework of pipeline culpability may offer a tool for impacted communities to rebuff such moves. Allied together, they may further impress upon policy makers the aggregate harm caused by the industry's ecology of production. Both coastal and inland fence-line communities are ensnared by a fossil fuel industry that is highly supported and subsidized by tax-abatements, zoning ordinances, and industry-friendly laws—to say nothing of the massive federal subsidy in the form of flood control.[1] Both coastal and inland fence line communities also happen to be predominantly African American, Latinx, Indigenous and low-income White communities with little access to financial and political resources. They instead live in areas that are sacrificed, as if nodes on a single Energy Sacrifice Zone continuum.

While this framework may seem abstract, conceptual frameworks are critical for activating public interest and scrutiny about an industry that benefits from concealment in many ways. Impacted communities must use every available conceptual tool to illustrate what industry insiders do not always want to reveal. The U.S. pipeline system includes 207,000 miles of mainly subterranean interstate and intrastate pipelines that carry crude, natural gas and petroleum products beneath the ground of 300 million American consumers. Another 300,000 miles of transmission pipelines transport natural gas over long distances from wellhead to storage and onto plants (AFPM 2018). Their enclosed delivery conceals them from public consciousness. Sometimes we experience them as part of a kind of esthetic of technical sublime. Petrochemical companies light up the nighttime Mississippi River corridor like futuristic lunar colonies. The writer John McPhee once noted that Louisiana's industrial plants on the Mississippi "made the river glow like a worm" (McPhee 1987).

Meanwhile, the enclosed capture and distribution of liquid hydrocarbons precludes opportunities for democratic action by workers and affected residents, according to scholar Timothy Mitchell. Their networks of production are less visible than earlier forms of labor-intensive energy extraction such as coal mining. Instead of manual production and railway transportation that historically enabled chokepoints for labor solidarity actions by striking coal miners, liquid hydrocarbons utilize pumping stations and pipelines for transport from extraction sites to processing destinations (Mitchell 2009). Pumping stations rarely go on strike. Without public scrutiny on channels of distribution, pipelines function without much attention. They become naturalized into landscapes.

What is required, then, is a framework that illuminates the net harm rendered by this assemblage. Such a framework would expand the geographic boundaries of the zone itself.

[1]In 2018, the Louisiana Legislature made trespassing on or near oil and gas pipelines felonies punishable for up to 5 years in prison and/or $1,000 fine. Yet state law allows pipeline companies wide discretion to seize or "expropriate" private land by eminent domain.

I argue that such zones need not be adjacent to one another to be considered logically contiguous and, therefore, connected by the infrastructure of fossil fuel extraction, production and distribution. This zone of harm, once established, could be used to inform decision makers with a more accurate and complex picture of social and public health costs of current and future industrial projects associated with fossil fuel and petrochemical production as well as to determine legal culpability in restitution claims by communities bearing the burden of the carbon economy.

The following sections of the article will provide some historic background to the definition and use of Sacrifice Zones as a discursive frame by actors to illustrate the relationship between land-use decisions and environmental racism, as well as by authorities as a necessary sacrifice for the public good. The article will build a conceptual framework for pipeline culpability by showing the tight coupling between the oil and gas extractive industry and downstream, value added refinement and petrochemical production. The article then applies this framework to the state of Louisiana as a case study, focusing on the harm that extraction and production practices have had on coastal indigenous residents in Louisiana and then on inland residents within the Mississippi corridor, dubiously known as "Cancer Alley." It examines some modes of resistance that community residents have taken and concludes with the need to bolster community resistance with a conceptual framework that can bring multiple communities into solidarity alliance (**Figure 1**).

DEFINING SACRIFICE ZONES

Here, I discuss the proposed theoretical framework and history of the Sacrifice Zone. I use the term *continuum of culpability* rather than ecology to underscore the continuity of the infrastructure and associated business and political networks among the practices of extraction, conveyance and inland production. Refinement and petrochemical processing once belonged to single, vertically integrated companies that drew liquid hydrocarbons from the ground and moved them to refineries and petrochemical operations. Inland plants that manufactured petroleum-based products created a secondary market for oil and natural gas, which added value to the supply chain. Today, these functions may be undertaken by separate entities, but they operate within a tight, vertically-integrated market with revolving boards of directors, lobbyists, supportive law makers business councils, and trade groups such as the U.S. Chamber of Commerce and American Petroleum Institute that fund deceptive marketing campaigns through proxy organizations. I have chosen to focus specifically on Louisiana to illustrate this tight industrial continuum, but such a framework may also be expanded to inter-regional and international constellations of symbiotic operations. As a heuristic, the term "Sacrifice Zone" has been used by a number of actors, activists, scientists, and even government officials to index areas and communities that have been permanently sacrificed for ostensibly greater causes (Bullard 2011; Holifield and Day 2017; Lerner 2019). The phrase tacitly acknowledges that harm visited upon some communities benefits others (Bullard et al., 2007; Maldonado 2018; Lerner 2019).

Popularized as a Cold War reference, Sacrifice Zones were designated by the government as areas made uninhabitable by military use. The nuclear arms race between the United States and Soviet Union left large areas in both nations contaminated with radioactivity. Due to the sheer number of areas and expense of soil remediation, many of these polluted, irradiated areas were abandoned, fenced off, and posted with

FIGURE 1 | Warning signs like this one near Pointe-au-Chien in Terrebonne Parish dot the coast. Credit: Kerry Maloney.

warning signs. "The areas contained within these fences began to be known by engineers working within the department as "Sacrifice Zones" (Lerner 2019). While government officials have conceded that the production of nuclear weapons caused citizens to "make health and economic sacrifices on the altar of national security," analogous sacrifices by other groups were long ignored. The health of a much larger host of low-income and minority Americans is regularly sacrificed to chemical contamination by private industrial plants. The contemporary deployment of Sacrifice Zones attempts to dramatize the fact that "low-income and minority populations, living adjacent to heavy industry and military bases are required to make disproportionate health and economic sacrifices that more affluent people can avoid" (Lerner 2019). Proposals to locate a new industrial facility adjacent to residential areas are often sold to a community in terms of the jobs it will create. This tradeoff may be viewed as a kind of "economic blackmail" foisted upon hardscrabble neighborhoods with otherwise little employment opportunities (Lerner 2005: 3). Areas that become Sacrifice Zones are typically zoned as residential/industrial, which is "a particularly pernicious type of zoning ordinance," where industrial facilities and residential homes stand side by side without adequate buffer zones (Lerner 2019). Negative health impacts predictably follow. "Residents along fence lines with heavy industry often experience elevated rates of respiratory disease, cancer, reproductive disorders, birth defects, learning disabilities, psychiatric disorders, eye problems, headaches, nose bleeds, skin rashes, and early death" (2019:6). Air pollution is compounded with "the stress and tension of noise and squalor" (Bullard and Wright 1986). This pattern of disproportionate exposure constitutes environmental racism—a pattern articulated in 1979 with *Bean v. Southwestern Waste Management,* which was the first lawsuit to use civil rights law to challenge environmental racism (Bullard 2011).

Heavy industry depresses property values, and what was sold as an economic booster becomes an economic drag. Residents become entrapped with added economic hurdles of poor real estate equity in undesirable areas, which real estate and land use professionals call "Locally Unwanted Land Uses" or LULUs. Study after study over the past 2 decades affirm that minority communities face an uneven pollution burden compared to White counterparts, even those with lower incomes. Researchers from the University of Colorado Boulder reported in 2008 that African Americans with household incomes between $50,000 and $60,000 live in neighborhoods that are, on average, more polluted than the White households that with $10,000 less in annual earnings (Downey and Hawkins 2008). African Americans are much more likely to live near toxic pollution and are exposed to 38 percent more air pollution than White Americans (Fleischman and Franklin 2017). Likewise, in neighborhoods with "clustered facilities," people of color make up 69 percent of nearby residents. Such disparities were repeated in nine of ten U.S. EPA regions and 40 of 44 states with hazardous waste (Bullard et al., 2007). Fines levied on polluting industries are also unequally portioned. An examination of 1,100 Superfund sites reveals that the average fine imposed on polluters in White areas was 506 percent higher than the average fine imposed in minority communities (Lerner 2019). Meanwhile, White residents experience a "pollution advantage" by exporting air pollution created in the goods they consume, according to a 2019 study in the *Proceedings of the National Academies of Sciences*. Whites are exposed to 17 percent less air pollution caused by the goods and services they consume, while Blacks and Hispanics bear a "pollution burden" of 56 percent and 63 percent excess exposure, respectively (Tessum et al., 2019).

With the addition of Geographic Information System (GIS) tools, researchers can identify demographic areas by race and income to further correlate that race is more subjected to environmental justice issues than poverty (Perera and Lam 2013). Such GIS mapping studies find pollution discrepancies based on race, income, and education up and down the Mississippi River corridor. For example, in the heavily industrialized St. James Parish in Cancer Alley (counties in Louisiana are referred to as parishes), a GIS study found that polluting industries were located in areas with the highest percentages of African Americans, the lowest average household income, and the most residents without a high-school diploma. Meanwhile, the residents employed by the plants tended to live the furthest away, were wealthier, better educated, and more likely to be White (Blodgett 2006).

While recent tools have given social scientists and community activists the ability to quantify harm visited upon minority neighborhoods, activists of color have been publicly resisting such patterns of oppression and poison across the United States since the 1960s, from California grape-pickers organized by Cesar Chavez to black students in Houston protesting the location of a city dump (Miller and Maxwell, 2017). "This is not the racism of epithets . . . rather it is more subtle but equally powerful and repellent racism of neglect. Much environmental racism is latent, covert—and overwhelming" (2017: 17). Today, many grassroots community leaders and environmental justice actions are led by women of color and retired persons. In other words, grandmothers are performing the work that government regulators should be doing (Bullard 2011). They often face punitive resistance by powerful state actors, including felony trespassing laws that make it a felony to protest near "critical infrastructures" such as petrochemical facilities or pipelines on land seized by fossil fuel companies under eminent domain (Thibaut 2018; Sneath 2020a).

THE SACRIFICIAL FRAME

Sacrificial frames can also be deployed by policy makers as a rationale to support heavy industry in impacted areas. In a study on shale fracking in Wisconsin, geographers Holifield and Day suggest that the frame of Sacrifice Zones indexes a rationale to justify the exploitation of areas in order to secure other common goods or "scales of security" such as energy independence

(2017). It appears to be deployed by a multitude of actors to imply and rationalize harm. For example, the exploitation of shale gas deposits in Wisconsin has been justified as a means to attain national energy security, while promoting economic security for depressed rural areas, job security for local households, and protection from global climate change (2017: 271) (**Figure 2**).

Here in Louisiana, authorities often invoke a sacrificial frame when it comes to the environmental costs of oil and gas extraction in the context of the state's coastal restoration narrative. Presentations by the Coastal Protection and Restoration Authority (CPRA), which oversees the Louisiana's $50 billion, 50-years Master Plan for a Sustainable Coast, tout the state's contribution to the nation's energy needs as a frame to underscore the importance of maintaining its "Working Coast" (Randolph 2018). In this way, the state's wetland loss, which is exacerbated by oil and gas extraction, is framed as an unavoidable sacrifice. In exchange, the state receives federal royalty collections on oil and gas drilling in federal waters, which are dedicated to funding the Master Plan. Prior to 2005, the state received practically nothing in royalties from deep-sea wells that carried liquid hydrocarbons from federal waters onshore through Louisiana's vast pipeline infrastructure. After Hurricane Katrina, then-U.S. Sen. Mary Landrieu, D-La. garnered support from sympathetic members of Congress to pass the Gulf of Mexico Energy Security Act, known as GOMESA, which significantly increased Louisiana's federal royalty share on drilling in the Outer Continental Shelf (Randolph 2020). She articulated her efforts through the frame of sacrifice. "These areas and their fragile environments in Louisiana were sacrificed long ago for the benefit of industry investment and development. I intend to ensure that these areas will be ignored no longer" (Theriot 2017: 187).

When Louisiana received a major haul from GOMESA in $87 million on oil royalties in 2018, state officials applauded the money as a recognition of the sacrifices the state had made for the nation's energy security. Sen. John Kennedy, R-La. wrote, "This money will help us restore our beautiful coast so that we can continue to provide oil, natural gas and seafood to the rest of the nation" (2018). Through the discursive frame of sacrifice, fossil fuel production is "Green-washed" as supporting Louisiana's coastal restoration efforts (Miller and Maxwell, 2017; Randolph 2018). In fact, the industry is repositioned as a critical asset and victim of coastal erosion and sea-level rise, despite its culpability for environmental damages.

The Case of Louisiana: From the Coast to Cancer Alley

Oil and gas industry practices of cutting canals, drilling wells, and laying pipelines cause irreparable harm to the coastal landscape. Notwithstanding greenhouse gas emissions, fossil fuel industry practices are cited in scientific literature as major contributors to Louisiana coastal land loss, which has totaled of 2,000 total square miles since 1930 (Baustian and Turner 2006; Morton, Bernier, and Barras 2006; Morton et al., 2010; Houck 2015; Couvillion et al., 2017; Theriot 2017; Turner 2018; Day et al., 2020). Pipeline and navigation canals cause a number of compounding effects. Ponding caused by spoil banks of canal ridges disrupts sedimentation and drainage, which impairs marsh vegetation needed to retain coastal mud and sediment (Turner and McClenachan 2018). Canals also channel salt-water into brackish estuaries. Spoilage of the brackish ecology accelerates the loss of marshland and bayous to open water, which threatens international migratory flyways and seafood and marine estuary nurseries. Coastal erosion also denudes storm protection for

FIGURE 2 | Louisiana has lost 2,000 square miles of coastal wetlands since 1930. Credit: Kerry Maloney.

coastal urban centers like New Orleans and smaller coastal communities. A traumatic storm event is then compounded by the loss of generational livelihoods, flooding to homes and businesses, and unaffordable insurance. That's in addition to leaks, accidents, blowouts, and spills from thousands of miles of aging subterranean pipeline infrastructure.

Louisiana far out spills every state in the nation, magnifying exposure of co-pollutants to marginalized communities (Meiners 2019). And at least 30 facilities in Louisiana marshes contain the most toxic chemicals allowable by the E.P.A., which makes them particularly dangerous during hurricanes. Harmful "spot plant flaring" legally releases tons of pollutants during emergency shutdowns, magnifying exposure of the toxic payloads inside plants are structurally at risk from storm damage, often unbeknownst to nearby residents (Bracket 2020; Sneath 2020b). Louisiana, additionally, has a problem of abandoned oil wells (Meiners 2019). A 2014 state auditor's report found that within state boundaries, there were nearly 58,000 neglected oil wells that were either abandoned or unregulated. So many, in fact, that the state cannot afford to plug them. Industry lobbyists perversely argue that the growing number of designated "orphaned" wells abandoned by out of compliance owners are too expensive to properly plug without maintaining the industry, whose taxes fund the orphan well program (Schleifstein 2020). When Hurricane Laura crashed through southwest Louisiana in the Fall 2020, it struck 480 "orphaned" wells that left behind miles of observable oil sheen throughout the marshes (Dermansky 2020). The 4,300 official "orphaned" oil wells alone would take $180 million and 20 years to plug (Schleifstein 2020).

Communities of color that live in increasing precarious areas are forced to reckon with these hazards that result in loss of health and livelihoods, disrupted generational connections, and coerced relocation (Maldonado 2018).[2] They are part of the violence that structures the social hierarchies of a place. Such oppression is even more perverse when those responsible for landscape degradation create a predatory relationship with victims of such practices. People with the least resources and legal knowledge to resist are burdened with presenting a cogent case of harm against powerful actors with the backing of state regulatory apparatus; a particular challenge when environmental degradation appears naturalized in the form of floods and storms, or as invisible toxins in the air and water. Such embedded, imbricated effects can be easily obfuscated (**Figure 3**).

Rather than a technical dilemma, environmental displacement is inherently social and racial, argues anthropologist Julie Maldonado. For example, offshore oil and gas extraction in coastal Louisiana has disproportionately impacted indigenous communities, who have borne the brunt of colonial, statist policy over generations (Maldonado 2014, 2018; Bisschop, Strobl, and Viollaz 2018). Maldonado characterizes the environmental impact of degraded areas—where the culpable actions have degraded the landscape—as tacit persecution. Recent press has highlighted the plight of coastal indigenous tribes in Louisiana. One tribe in particular has been held up as a harbinger for the challenge of relocation. Members of the state recognized Ilse de Jean Charles band of Biloxi-Chitimacha-Choctaw reside at a particularly vulnerable location that was left outside of the "Morganza to the Gulf" levee system when the U.S. Army Corps of Engineers (USACE) determined in 1998 that its protection was cost-prohibitive (Maldonado 2018; Alaska 2020).

The Challenge of Resettlement

The island has been inhabited by indigenous peoples since the early 1800s. Today, encircled by a small ring levee and connected by an easily flooded, two-lane road, the island has lost 98 percent of its landmass since 1955. Prodigious dredging by oil companies to lay pipelines, mark boundaries, and open navigation canals to oil platforms has torn apart the brackish estuaries. Saltwater intrusion and ponding effects that followed have killed the flora and destroyed tree roots that hold the land together. "Without tree roots, the surrounding land sinks, which makes it difficult for Tribes to grow their traditional fruits and vegetables and harvest medicinal plants" (Alaska 2020: 19). Meanwhile, dredging around the island has never been remediated. In the 1970s, the tribal residents successfully fought an attempt by the Louisiana Land and Exploration Company to dredge and dynamite through its burial mounds. The company never refilled the cut leading to the cemetery or other canals that surround the burial mounds (2020). In another incident, an oil company in 1992 sued eight tribal members of nearby Pointe-au-Chien who were fishing in their ancestral fishing, grounds … for trespass and damage to the property" (2020: 16). Meanwhile, wetland loss exposes the island to offshore storms that are growing more intense. "Rising sea level and increasingly intense hurricanes exacerbate these issues" (2020: 16) (**Figure 4**).

For 2 decades, the Isle de Jean Charles Tribe has been working on a resettlement plan that would also reunite members who have forced to leave the island over the years. Hurricane Lili in 2002 forced over 50 families to leave from severe flooding and damage, for example (Camardelle 2020). Since 2010, the Tribe has been working with a technical team on climate adaption and community planning to write a resettlement plan. In 2014, the Tribe along with its nonprofit partner, the Lowland Center, entered into an application with the Louisiana Office of Community Development (OCD) for a National Disaster Resilience Competition that called for innovative community responses to the devasting effects of climate change (Ilse de Jean Charles; OCD 2015).

Louisiana received a $92.6 million grant in January of 2016, which included $48.3 million for resettling Ilse de Jean Charles. The grant was the first federally funded initiative for voluntary community resettlement (Simms et al., 2021). In laudatory language, the award would "provide a safe resettlement for members of the Isle de Jean Charles tribe who are descendants of the historic Biloxi, Chitimacha, and Choctaw tribes through "blood lineage and cultural heritage" (Lowland 2016; EESI 2016; Isle de Jean Charles Tribe, 2021). However, what followed illustrates the vast challenges of managed retreat, particularly concerning indigenous communities (Maldonado 2014; 2018). A climate of distrust pervades interactions between state actors and indigenous

[2]Populations surrounding facilities with enough toxic storage onsite to warrant risk management plans are 11 percent more likely to be communities of color, 10 percent more likely to be low income, and 3 percent more likely to be linguistically isolated, according to the EPA.

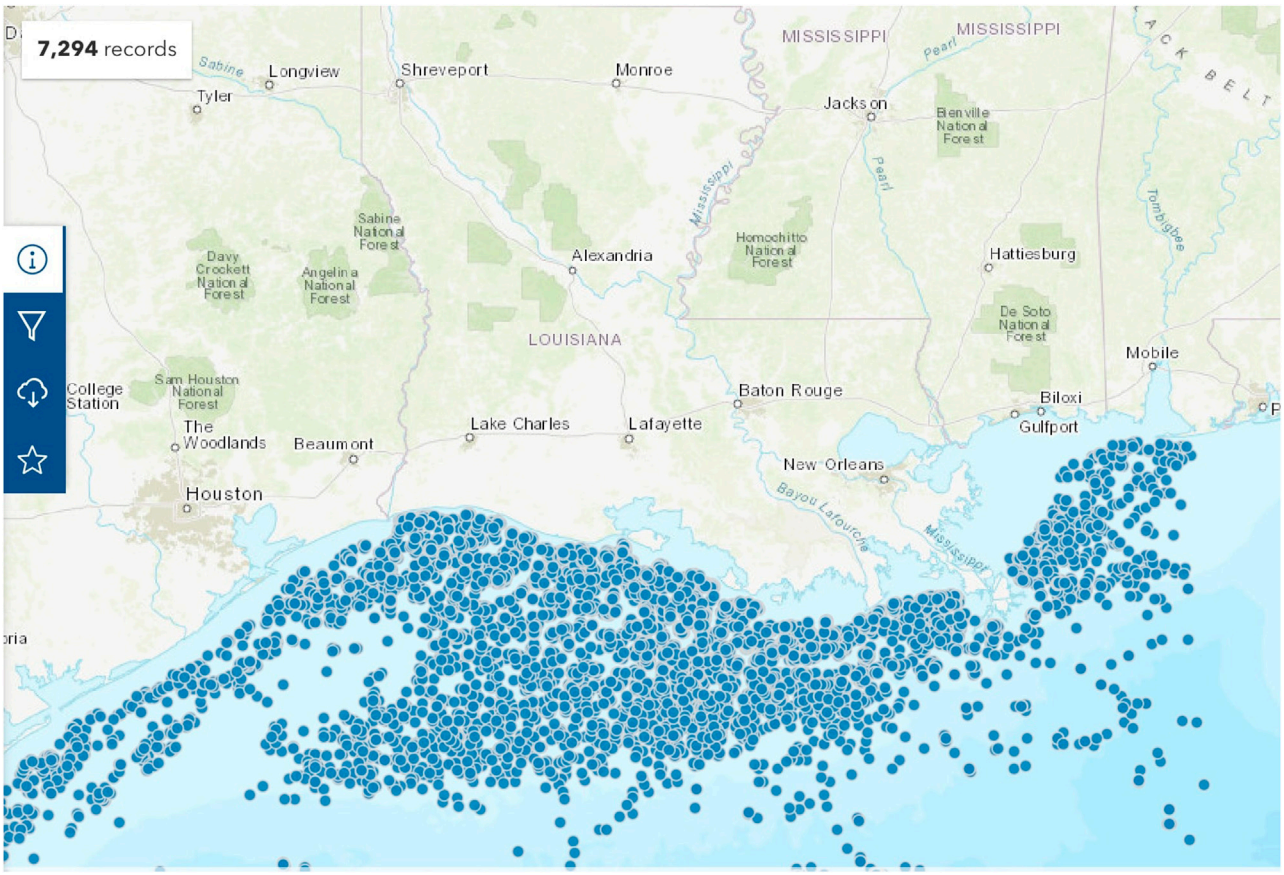

FIGURE 3 | Offshore oil and gas platforms off the coast of Louisiana and East Texas. Credit: Energy Information Administration (EIS) U.S. Energy Atlas.

FIGURE 4 | Isle de Jean Charles, home to a Louisiana indigenous community, has lost 98 percent of its land mass since 1955. Credit: Kerry Maloney.

communities, which reflects a history of land prospecting, theft, rural gentrification and the thwarted attempts to resettle island residents (Simms et al., 2021). All of which can derail even goodwill attempts—as happened in Louisiana. "The current distrust, steeped in the deep memory of land stolen and promises broken, appeared in the rumors and misinformation that led to the creation of powerful competing narratives about the (HUD) grant" (Simms et al., 2021: 5). While the initial grant application and award announcements by federal and state agencies referred specifically to tribal affiliation with Isle de Jean Charles band of Biloxi-Chitimacha-Choctaw, the terms of the grant began to change as others came forward. The Louisiana OCD later said referring to a single tribe rather on the island was a mistake (Alaska 2020: Appendix F). Shortly after the grant announcement, the OCD was approached by leadership from the state-recognized United Houma Nation asserting that some of its members also resided on the island (2020: Appendix F). In March 2016, OCD released a fact sheet for the award, which asserted that "tribal affiliation" would not be a part of the resettlement plan (Alaska 2020). Frustrated, in October 2018 the Isle de Jean Charles Tribal Council wrote to the Director of Office of Block Grant Assistance at HUD to recommend that the grant funds be returned to the National Disaster Resilience Competition grant committee (Alaska 2020: 52–53). Tribal members were also informed through the 2018 Permanent Relocation & Homeownership Assistance Program they would have to relinquish their island properties if they resettled (Alaska 2020). That requirement has been modified to allow residents to maintain their island properties for part-time use as long as the no new construction takes place and no extensive repairs to storm damage are undertaken (Alaska 2020: Appendix G). Isle de Jean Charles members were also disheartened to learn that funded resettlement would not extend to members who left the island prior to Hurricane Isaac in 2012, dashing hopes for reunification (Alaska 2020).

After learning about residents of the island who identify with the United Houma Nation, the state OCD conducted an island inventory, noting that some residents maintain Ilse de Jean Charles Tribal membership, while others maintain United Houma Nation membership and at least two residents are unsure about their affiliation. The OCD wrote that it discovered on the island a "diverse community of sometimes competing tribal interests" (Amendment, 2019: 4). The OCD formed a steering committee, which included five island residents, representatives from both the Isle de Jean Charles Tribe and United Houma Nation tribal councils, a representative from Terrebonne Parish government, and a representative from the Governor's Office of Indian Affairs.

On February 21, 2019, the OCD presented its new plans before the Houma-Terrebonne Parish Planning Commission. Several chiefs of state coastal tribes objected. The Pointe-au-Chien Indian Tribe sent a public comment letter in response, noting that the changes minimize both the existence and leadership of the Isle de Jean Charles Tribe and other coastal tribes. (Alaska 2020: 55–56). The OCD responded in May 2019 that the state cannot legally acknowledge the tribes as sovereign because they are not federally recognized by the Bureau of Indian Affairs (Alaska 2020: 56–61). Attempting to contextualize changes to the resettlement plan, the state said it had already presented a framework for community resettlement for threatened areas, and was looking for a specific resettlement project to propose. The Isle de Jean Charles Tribe, also known as the Isle de Charles Band of Biloxi-Chitimacha Confederation of Muskogees (BCCM), had been working on such a plan for some time. "Concurrently, tribal leadership of BCCM provided the state with a basic narrative." The narrative, said OCD, was that the island was synonymous with Isle de Jean Charles Tribe. In following the Tribe's narrative as presented, resettling the tribe would represent an ideal example of the community resettlement concept outlined in the state's Phase I submission. "Having no reason to question this description of Isle de Jean Charles at the time, the state described in its Phase II submission the resettlement project accordingly" (Alaska, 2020: Amendment F).

Three years after the grant announcement, the state submitted an amended resettlement plan, which HUD approved in August 2019, to offer resettlement to anyone who resided on the island after 2012. "Regardless of which tribe residents and former residents identify with, the resettlement is, by federal law and the state's desire, not tied to any particular tribe, race or belief system," the amended plan said (Amendment, 2019). In response, the Ilse de Jean Charles Tribe charged that the state violated its right to self-determination. The Tribe joined with three other Louisiana coastal tribes and the Native Village of Kivalina of Alaska in a complaint, dated January 15, 2020, to the United Nations claiming human rights violations "as a consequence of the U.S. government's failure to protect, promote and fulfill each Tribe's right to self-determination to protect Tribal members from climate impacts" (Alaska 2020: 3). In the complaint, Isle de Jean Charles Tribe said the Louisiana Office of Community Development substantially changed the resettlement plan without consulting Tribal leadership, and in some cases, took major action without notifying the Tribe (Alaska 2020).

The OCD in 2020 moved forward with the amended plan, using $12 million of the HUD grant to purchase a former 515-acre sugar farm 40 miles north of the island. Construction is scheduled to be completed by the end of 2022 (Simms et al., 2021). The Isle de Jean Charles Tribe said it learned of the purchase through a press release. The Tribe said it had officially withdrawn from the settlement plans (Alaska 2020). Frankly, the resettlement process was much more complex than originally expected, noted the U.S. General Accounting Office. "Tribal leaders from both of the state-recognized tribes have expressed concern that the process does not meet the unique needs of tribal residents." Some tribal residents have chosen not to relocate, and will remain vulnerable to coastal erosion and storm surge, increasing the likelihood that they will be impacted by a disaster event (GAO 2020).

The difficulty of resettlement, a disruptive process in its own right, is illustrative of the immense sociological challenge that coastal land loss presents to governing structures. Not only does sea-level rise threaten key ecological and economic resources, but the social impact of people forced to relocate as well as

communities that might absorb them presents an array of opinions about what self-sufficiency and/or restitution should comprise (Laska et al., 2005; Maldonado 2018; Hemmerling et al., 2020; Simms et al., 2021).

The Case of Louisiana: An Inland Secondary Market

The pipeline infrastructure that causes so much coastal destruction carries billions of barrels of oil and trillions of cubic feet of natural gas (produced onshore and offshore) across Louisiana's tidal marshlands through an intricate and aging network of pipelines. Pipelines carry gas and petroleum feedstock to refineries and petrochemical plants dotted along the 85-mile Mississippi River industrial corridor, where inland "fence-line" communities live on the front-lines of direct industrial exposure (Bullard and Wright 1986; Bullard 2011; Lerner 2019). This massive secondary market was drawn to the region by inexpensive oil and natural gas, unlimited supplies of water in the Mississippi River, inexpensive labor, loose regulatory oversight and massive tax breaks (McMichael 1961; Peterson 2000; Allen 2001; Leber 2020). In general terms, petrochemicals are chemicals derived from "substances or materials manufactured from a component of crude oil or natural gas" (McMichael 1961: 24). Starting in the 1950s, oil refineries began to "mine" their process streams for compounds to make higher value products. Shell in Emeryville, Calif., and Standard Oil of New Jersey began studying derivatives of their raw materials. By the mid-1950s American Cyanamid had expanded its operations into Louisiana followed by Monsanto to produce fertilizer and ammonia (Peterson 2000: 10). From 1956 to 1955, approximately, $600 million was invested in new and expanding petrochemical plants in Louisiana (McMichael 1961). "From 1964 to 1968 ... petrochemical growth in Louisiana outpaced all other states, including Texas" (Allen 2001: 178; Scott, 2005). Companies like Union Carbide and Dow Chemical Co. relocated there. Refineries such as Shell Petroleum Company generated chemical sister plants for secondary markets for newly-discovered products like antifreeze, tires, plastic food containers trash bags, laundry detergent (Lerner 2005: 24). In the late 1960s, demand for fertilizers surged. Louisiana became a favorite spot for new ammonia plants, again predicated on the availability of cheap oil and gas feedstock (Peterson 2000: 10). The plastic boom followed with dozens of plants manufacturing Polyvinyl Chloride (PVC), Polypropylene, synthetic rubber, Polystyrene, Melamine Crystal, Isocyanates for Urethanes (Peterson 2000). "The petrochemical plants have to a large extent located where they may obtain the refinery off gases which formerly were burned as fuel or flare gas," Robert Nance McMichael, wrote in his 1961 dissertation entitled *Plant Location Factors in the Petrochemical Industry in Louisiana* (EPA, 2021). "It has been estimated that approximately 50 percent of the petrochemical raw materials are by-products of refining operations. It would be expected, then, that petrochemical plants would be most common where the greatest concentration of refineries are found" (40) (**Figure 5**).

With the passage of the 1966 Federal Water Quality Act, companies began factoring pollution into their costs. Rivers with a high discharge rate like the Mississippi River made an ideal location in light of coming regulations (Allen, 2001: 179). Even more chemical plants and refineries began dotting the landscape of former plantation lands, where multiple generations of descendants of slaves and sharecroppers lived (Williams 2018). "A number of these plants bought their riverfront property from former white plantation owners who then moved, leaving their poorer and minority neighbors behind" (Allen 2001). "Enabled by state zoning, a wave of chemical plants dropped on African American communities like a bomb" (Houck 2019: 472).

Infrastructural pipelines and petrochemical plants did not spontaneously appear at the doorsteps of poor, largely African American communities. Rather, they are part of a historic continuum. Scholars have noted the historic and geographic connections between the slave plantation and chemical regime (Green 2015; Garrigus and Hall 1994; Steve Lerner 2005; 2019). Yet more research is needed to carefully map these relationships. The economies of scale of sugar plantations required large plots of land with proximity to the river. In Cancer Alley, this arrangement is quite stark. "They had by no means moved to the nuisance. Following the Civil War their towns arose next to the old plantations, and the industry that followed later simply introduced another plantation culture of its own, low wages, minimal employment and the profits going as far away as Germany and Japan" (Houck 2019: 459) Names such as the Diamond Plantation, Trepagnier and Good Hope Plantations became ideal sites in the 20th century for bringing oil ashore for storage and refining. "This exchange of land use—'from plantation to plant'—has exposed local residents, many of whom descend from slaves, to the life-limiting and protracted threat of harmful pollution" (Davies 2019: 9). Some of the industrial operators restored the ornate antebellum homes. Famous plantations such as Ashland-Belle Helene, Destrehan, San Francisco and Aillet House were purchased by Shell Chemical Amoco, Marathon Oil and Dow Chemical (Peterson 2000: 8). Restoration efforts are aided by historic preservation grants, which are not afforded to proximal historic areas associated with communities of color. Such practices, note scholars, preserve the esthetics of White Supremacy.

Nearly 200 years ago, the same area was the epicenter of the largest slave rebellion in U.S. history. Conditions were particularly harsh as river parish slaves cleared swamps, built levees and worked the fields. African slaves ran indigo processing facilities and, later, sugar mills. Slaves were lost to disease or suffered injuries in the fields and sugarhouses during grinding season. (Hall, 1992; Seck 2014; CEI 2020). Geographically, Louisiana was used as a threatened destination by masters whose slaves were not obedient. They could be sold 'down the river.' One of the legacies of

such operations in today's Cancer Alley is a community called Freetown in St. James Parish. Situated on the site of the former Pedescleaux-Landry Sugar Plantation, Freetown just decades ago was a bucolic agricultural community. It was founded by former slaves during Reconstruction in 1872. Many of the existing residents have lineage to this era, well before the petrochemical plants began moving in next door (Davies 2019). The degradation of Freetown happened relatively slowly, which according to Rob Nixon constitutes the slow violence of pollution, which strands a community in a place and strips it of the characteristics that made it livable (Davies 2019).

Today, there are 156 industrial chemical plants and refineries in Cancer Alley. This massive "oil assemblage" of plants produces everything from insecticides, and fertilizers to jet fuel and neoprene rubber. The corridor also hosts the world's largest manufacturer of Styrofoam (Baurick and Younes 2019; Tristan et al., 2019). Louisiana is the second highest top producer of U.S. petrochemicals in an area much more condensed than the top producer, Texas. While the petrochemical corridor is touted by advocates as an important source for thousands of manufacturing jobs, its other moniker speaks to the terrible health outcomes and environmental racism that befalls on fence line communities, which are exposed to the nation's highest concentrations of chemicals linked to cancers and other respiratory and prenatal illnesses.

The production of known carcinogens is well documented, but there is less precision about quantifying harm to residents. State regulators often downplay health claims, citing the Louisiana Tumor Registry that shows nominal elevations of documented cancer rates. Critics say the registry casts too wide a geographical net and fails to account for higher incidences of cancer closer to plants. The registry also fails to document the constellation of illnesses other than cancer, such as respiratory diseases, skin irritations, mental impacts and prenatal miscarriages.

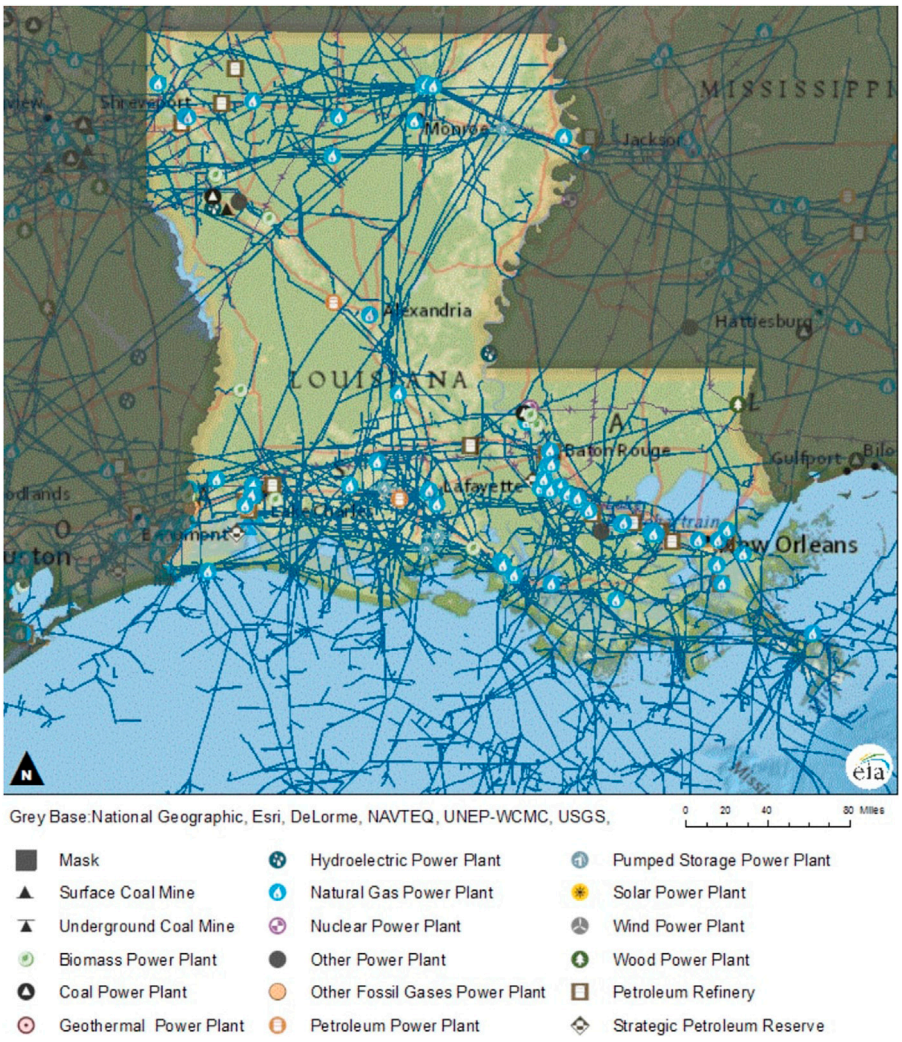

FIGURE 5 | South Louisiana's pipeline infrastructure. Credit: Energy Information Administration.

This leaves impacted neighbors to offer anecdotal accounts to rebut official estimates. "Proof of causation in the case of cancer or any other suspected environmentally-related disease is difficult to produce," writes Barbara Allen (2001: 193). Such a study would need to analyze not only those living in the proximity of plants, but also adjust for those who also drink, smoke, or have a genetic disposition to cancer. Length and concentration of exposure would have to be factored in, plus many other factors. "The beneficiary of this inaction is the chemical industry, which can unequivocally state that there is no proof of their pollution harms neighboring residents" (2001: 193).

There is also little granular air monitoring by federal or state agencies. Instead, the EPA models a "Risk-Screening Environmental Indicator" database to identify potential high-pollution areas. A 2020 investigation analyzed the EPA's database and found that the seven Louisiana parishes along the Mississippi River Corridor from Baton Rouge to New Orleans contain 200 plants that emit toxic chemicals at a high enough level that they must report their emissions to the government (Baurick and Younes 2019).

Louisiana has the highest toxic air emissions per square mile of any state, based on data gathered by the U.S. Environmental Protection Agency's 2018 Toxics Release Inventory. The state in 2018 averaged 1,239 pounds of toxic air releases per square mile, well ahead of runner-up Ohio with 899 pounds per square mile (Jacobs, 2021; Schleifstein, 2021). The chemical industry in Louisiana annually generates the equivalent of 16,000 pounds of hazardous waste for every resident of Louisiana, which is more than 12 percent of all hazardous waste in the United States. It also imports waste from other areas. "The region now has dozens of hazardous-waste incinerators and chemical landfills that line the river, many of them exempt from federal hazardous-waste disposal regulations" (Allen 2001: 180). That includes radioactive material.

In the next section I will examine conditions in three parishes in Cancer Alley where plant expansions are pending. This is not, however, an exhaustive account.

Inside Cancer Alley: The Case of St. James Parish

In the single community of Convent, a small town on the Mississippi River in St. James Parish between Baton Rouge and New Orleans, 11 chemical plants lay within a few miles of the town which is 80 percent African American with a 40 percent poverty rate. When the Japanese plastics manufacturer Shintech proposed a new facility there in 1995, the area's emissions already amounted to 250,000 pounds of toxic air per mile—which was 658 times the national average. The Director of Tulane Environmental Law Clinic wrote that a person who spent a half day in Convent would be exposed to as much toxic air pollution as the average American breathes in a year. Between 1994 and 1997, there were 141 emergency toxic releases reported (three per month) in the Convent area, which forced school closures and residents to shelter in place (Houck 2019). Nonetheless, Shintech was awarded the project.

Currently, there are proposals to build or expand three plants in St. James Parish, where 14 percent of the land is owned by chemical companies and over 40 percent of the parish is wetlands. In 2014, the parish passed its first land-use ordinance, which quietly rezoned to a large portions of its predominantly black 5th District from residential to residential/industrial. Meanwhile, two chemical companies—Petroplex and Wolverine—were around the same time barred from building new facilities across the river in the predominantly White 3rd District. Clyde Cooper is the 5th District Council member. "It's a decision based on 'We don't want it in the white area but we don't mind it being in the black area'" (Kardas-Nelson 2019). Several of St. James's Parish Council members, including the president, are current or former employees of the petrochemical industry. Data collected there shows that residents have been exposed to emissions that can reach 765 times the levels considered safe by the EPA (Kardas-Nelson, 2019).

Inside Cancer Alley: The Case of St. John the Baptist Parish

In 2018, the EPA reported that St. John the Baptist Parish had one of the highest cancer risks in the nation from the "likely carcinogens" Chloroprene and Ethylene Oxide.[3] Not incidental, the Denka Performance Elastomer plant the town of La Place in St. John the Baptist Parish is the only site in the nation that emits Chloroprene, which is used to produce the synthetic rubber Neoprene (EPA). In 2020, the EPA's Office of Inspector General identified La Place along with three other sites in Cancer Alley among the top 24 of the highest risk areas that needed to be urgently alerted about health hazards of nearby Ethylene Oxide-emitting facilities, which the EPA in 2016 determined to be 30 times more carcinogenic to adults than its prior estimates. The 2020 report entitled: "Management Alert: Prompt Action Needed to Inform Residents Living Near Ethylene Oxide-Emitting Facilities About Health Concerns and Actions to Address Those Concerns." (O'Donnell 2020). At the time of the report, none of the communities had been contacted by federal regulators. Around the same time the EPA was temporarily relaxing regulatory reporting requirements for plants in Cancer Alley in response to COVID-19, which was also killing residents due to pre-morbidities associated with respiratory problems and race (EPA 2020; Terrell and James 2020).

[3]In May 2021, the EPA Inspector General announced that the agency should conduct new risk reviews for sites that emit Chloroprene and Ethylene Oxide in order to protect the health of communities that face "unacceptable health risks" from exposure.

Inside Cancer Alley: The Case of Iberville Parish

In the town of Plaquemine in Iberville Parish, which is on the west side of the Mississippi River across from Baton Rouge, the second Shintech plant, which makes ethylene, was in 2019 greenlighted for a $1.5 billion, 300-acre expansion, which would intensify pollution in an area where an EPA model estimates the toxic levels of cancer-causing chemicals to be double the already high Iberville Parish average. (Baurick and Younes 2019). "Plants like Shintech contribute to those high levels. In the nearby community of Bayou Goula, when Shintech expands, the toxic air levels are expected to worsen by up to 16 percent" (Younes 2019). Also in Iberville Parish, the predominantly African-American community of St. Gabriel has one petrochemical plant for every 656 residents. There are 30 large petrochemical plants within 10 miles of St. Gabriel. Thirteen are within a 3-mile radius. "A mile outside of town is the world's largest manufacturer of polystyrene, commonly known as Styrofoam" (Baurick and Younes 2019). Exposure to cancer-causing emissions within the two-mile radius of those plants is 800 times higher than an average, according to the EPA's National Air Toxics Assessment, which was published in December 2015. Other census tracts near the plant had risks of exposure to cancer-causing emissions that are over 200, 300, and 400 times higher that national average (EPA 2015; Lerner 2017). Just next door in Ascension Parish, Louisiana Gov. John Bel Edwards announced his support for a new plant by Mitsubishi Chemical Corporation, which is considering building a large Methyl Methacrylate chemical plant, subsidized by $4 million in state tax incentives (Perilloux 2020).

Inadequate Regulation

While they bear the brunt of pollution, these communities likewise suffer from inadequate protections from Louisiana Department of Environmental Quality (DEQ), which is charged with regulating the plants. The enforcement agency only considers the effects of individual chemicals emitted by plants, instead of considering the holistic impact of their combined effects. Nor does not conduct or mandate regular air monitoring (Baurick and Younes 2019; Terrell and James 2020). "Instead, Louisiana depends on information from the plants to estimate that ambient standards are met and are not violated by one or more sources" (Flatt 2007). Louisiana also does not require plants do their own risk analysis. And Louisiana's choice of a residual risk level is 100-times greater than the more accepted standard of excess cancer deaths of one in one million (2007).

In January of 2021, the Louisiana Legislative Auditor issued a scathing report of the inadequate enforcement practices by DEQ. The auditor's report found that it took nearly 20 months for DEQ to issue enforcement actions after a plant operator failed to properly report emission violations. "Auditors also found it could take as long as 9 years from the time a company was cited for violating emission standards before it was ordered to pay a fine or had a settlement approved requiring the company to pay for a mitigation project." (Schleifstein, 2021). That means the plant could excessively pollute for more than a decade before being forced to stop. The enforcement agency also doesn't adequately track the penalties it has assessed or whether penalties were even paid. Plant reports are mailed to DEQ and then manually scanned into the agency's database, which the audit says results in unreliable reporting on when and whether the reports were received (Jacobs 2021).

In effect, any earnest attempt to correlate hazards with emissions and its impact on communities are left to the residents themselves. Residents with deep intergenerational ties who wish to exercise local land-use sovereignty find themselves up against legal resources of multi-billion corporations as well as the willful state complicity and often punitive laws. One of the legal strategies by communities to fight petrochemical expansions has been to highlight that these

FIGURE 6 | Community members have used multiple tactics and civil resistance to call attention to chemical pollution. Pictured here in a 2018 march against the construction of the Bayou Bridge Pipeline. Credit: Marc Pagani for the Louisiana Bucket Brigade.

plants are churning out single-use plastic products that end up polluting streams and waterways. Their production also contributes to greenhouse gases, as Louisiana already ranks among the top three states in the nation of per capita energy consumption because of its petrochemical and oil and gas industries (EIA 2018). Affected communities have employed different tactics and strategies to win legal settlements and educate and mobilize residents. Some have successfully blocked or delayed new permit approvals. Residents like Sharon Lavigne of Rise St. James joined with several environmental groups in a lawsuit against the U.S. Army Corps of Engineers in January 2020 to stop construction of a Taiwan-based plastics company, Formosa Petrochemical, to build a $9.4 billion Ethylene Oxide and Benzene plant the Fifth District of St. James. According to its air permit application, Formosa would be one of the single largest emitters of Ethylene Oxide and Benzene (both carcinogens) in the state (Kardas-Nelson 2019). Rise St. James alleges that the Army Corps of Engineers failed to disclose the environmental damage and public health risks of the plastics facility under the National Environmental Policy Act. Rise St. James cited a number of environmental factors: loss of wetlands in construction, pollution of single-use plastics, and toxic emissions. They also allege that the Corps failed to adequately consider the harm to slave burial grounds on the site, which is a violation of the National Historic Preservation Act: "(T)he Plastics Facility is sited on two 19th century sugarcane plantations, which include two cemeteries that contain the remains of enslaved people" (CEI 2020; Rise St. James et al., 2020). The Corps announced on Nov. 14, 2020 that it would reevaluate its wetlands permit for Formosa Plastics. On Nov. 18, 2020 a state judge sent air permits for Formosa's project back to DEQ, directing the agency to take a closer look at how the plastics facility's emissions will impact the predominantly Black community living nearby (D. Mitchell 2020). Yet there are billions of dollars proposed projects along the river corridor still coming (Baurick and Younes 2019; Staff Editorial, 2019; Perilloux 2020) (**Figure 6**).

Conclusion: Surprising Challenges and Opportunities

In "Carbon Democracy," Mitchell posits that the oil industry is particularly unique in the history of energy because it exists as part of a vast "technical zone" that relies on a set of coordinated yet dispersed "regulations, calculative arrangements, infrastructures and technical procedures" that allows its flows to be governable and predictable (2009: 409). It requires, in essence, a production of scarcity, which is maintained through national economic and legal policy and geo political arrangements with producers and buyers—which today must also reckon with a glut of capacity from gas fracking and consumer backlash. The industry is over-supplied and financially leveraged as demand falls because of macro-level global downturns, international concerns on global warming, and falling costs of sustainable energy alternatives. As a result, the oil industry is reliant on increasing a secondary plastics market to maintain demand and justify future activity. Planning documentation indicates that fossil fuel producers see their future in increased plastics production to offset global downturn fossil fuels. As a whole, the oil and gas industry aims to increase plastic feedstock production by at least 33 percent by 2025 (CIEL 2017).

This secondary market of petrochemicals is part of a logical and physical continuum of the domestic oil and natural gas industry, which includes physical pipelines and "midstream infrastructure" of petrochemical plants and other channels of distribution. Other ancillary subsidies include regulatory rollbacks, tax incentives, disregard of public health assessments, and even laws penalizing trespassers protesting plant expansions. The symbiosis between fossil fuel extraction and inland refining and petrochemical manufacturing is supported by material pipelines as well as enabling logics of manufactured scarcity from increased secondary market demand, complicit regulators, and marginalized communities. There must be an extended connection between points of culpability to link the origin and destination sites. I therefore suggest that any restitution or protests of resistance can be enriched by connecting impacted communities along the pipeline to create an expanded Sacrifice Zone. This framework can make visible the true ecologies of production, harm and sacrifice from the coast to Cancer Alley or even from continental gas fracking sites whose pipelines connect to plants in Cancer Alley. By designating these multiple sites as singular Sacrifice Zones, local communities can organize in larger blocs as they attempt to seek some kind of restitution from fossil fuel actors and state regulators. Through a larger alliance of solitary, the hope is that affected communities can better determine the fate of their immediate environment; and perhaps win legal restitution to decide whether to accept potential property buyouts or remain in place, while demanding more stringent regulatory attention to their toxic exposure.

As we move forward in thinking about strategies to respond to a changing climate, and possible terms of mitigation, restitution, resettlement or adaption, it's imperative to remember that the harm of a changing climate presents tremendous social challenges to population groups that are linked in surprising ways. Climate studies and its wide implications for not only technical challenges, but one that is immensely social and political. Solutions and responses will undoubtedly require social alliances to foster robust resilience and new imaginings of possibility for impacted communities.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

The author confirms being the sole contributor of this work and has approved it for publication.

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Diminishing Opportunities for Sustainability of Coastal Cities in the Anthropocene: A Review

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The world is urbanizing most rapidly in tropical to sub-temperate areas and in coastal zones. Climate change along with other global change forcings will diminish the opportunities for sustainability of cities, especially in coastal areas in low-income countries. Climate forcings include global temperature and heatwave increases that are expanding the equatorial tropical belt, sea-level rise, an increase in the frequency of the most intense tropical cyclones, both increases and decreases in freshwater inputs to coastal zones, and increasingly severe extreme precipitation events, droughts, freshwater shortages, heat waves, and wildfires. Current climate impacts are already strongly influencing natural and human systems. Because of proximity to several key warming variables such as sea-level rise and increasing frequency and intensity of heatwaves, coastal cities are a leading indicator of what may occur worldwide. Climate change alone will diminish the sustainability and resilience of coastal cities, especially in the tropical-subtropical belt, but combined with other global changes, this suite of forcings represents an existential threat, especially for coastal cities. Urbanization has coincided with orders of magnitude increases in per capita GDP, energy use and greenhouse gas emissions, which in turn has led to unprecedented demand for natural resources and degradation of natural systems and more expensive infrastructure to sustain the flows of these resources. Most resources to fuel cities are extracted from ex-urban areas far away from their point of final use. The urban transition over the last 200 years is a hallmark of the Anthropocene coinciding with large surges in use of energy, principally fossil fuels, population, consumption and economic growth, and environmental impacts such as natural system degradation and climate change. Fossil energy enabled and underwrote Anthropocene origins and fueled the dramatic expansion of modern urban systems. It will be difficult for renewable energy and other non-fossil energy sources to ramp up fast enough to fuel further urban growth and maintenance and reverse climate change all the while minimizing further environmental degradation. Given these trajectories, the future sustainability of cities and urbanization trends, especially in threatened areas like coastal zones in low-income countries in the tropical to sub-tropical belt, will likely diminish. Adaptation to climate change may be limited and challenging to implement, especially for low-income countries.

Keywords: climate change, Anthropocene, deltas, sustainability, tropical coasts, megacities

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INTRODUCTION

For thousands of years, human societies have lived relatively sustainably in coastal areas. The beginnings of civilizations as characterized by monumental architecture, large public works projects, social stratification and writing was intimately tied to many of the first urban developments. Many of the first cities worldwide occurred in coastal areas and soil-rich lower river valleys where high natural resource energies subsidized the flowering of culture (Day et al., 2007; Day et al., 2012; Marquet et al., 2012; Gunn et al., 2019). Turning to the modern era, urbanization was a hallmark of the 20th century with a majority of the world's population living in cities by 2010. The most urbanized countries have greater per capita GDP, energy use, and greenhouse gas emissions than predominantly rural countries (Burger et al., 2019). Coastal cities continue to be centers ever more so of economic activity, technological development, and culture. For example, Rappaport and Sachs (2002) reported that economic activities in the United States are overwhelmingly concentrated in coastal cities, which contribute very significantly to the nation's productivity and quality of life.

However, the 20th century was also a time of dramatic change in the biogeosphere and society. There was dramatic exponential growth in many aspects of the coupled natural-human systems, currently being characterized as the Anthropocene, including population, carbon dioxide in the atmosphere, the size of the human economy, energy use, natural resource extraction and utilization, and information generation (Brown et al., 2014; Steffen et al., 2015; Burger et al., 2019). Environmental degradation and species extinctions also rose dramatically (Steffen et al., 2018; Ceballos et al., 2020). Population rose by more than a factor of seven from 1800 to 2010, 1 to 7.7 billion, and total energy consumption by much more (Schramski et al., 2015; Syvitski et al., 2020). During this same period, the utility of cities changed as the number of people living in cities of a million or more rose by a factor of about 500. Around 2010, for the first time in human history, more than half of the world's population lived in cities—the *urban transition*. During the 19th and 20th centuries, the largest cities shifted from richer countries in higher latitudes (e.g., New York and London) to subtemperate and tropical areas and most urban growth is now taking place in developing countries and coastal areas. The combined impact of human activities has become so large that the earth moved into the new geological epoch, the Anthropocene (Steffen et al., 2018). Syvitski et al. (2020) report that human impacts had reached such high levels by the mid-20th century that the Earth System departed from its 10,000 years Holocene state to enter the Anthropocene.

Any consideration of the future of coastal cities must take into account the issues raised above. Coasts are at the forefront of global climate change impacts being led by sea-level rise, intense precipitation events, changes in freshwater input to the ocean, increased global warming and heat waves, poleward expansion of the tropical biological zone, increased intensity of tropical cyclones, and more extreme droughts and dramatic increases in wildfires. Each is discussed in more detail below. To these clearly global issues must be added local human impacts that are making coastal ecosystems and coastal cities less resilient and less sustainable. They include dams on rivers that reduce sediment input to coastal zones, massive water withdrawals from many rivers (e.g., the Tigris-Euphrates, Colorado, Nile and Indus), impoundment and reclamation of coastal areas, increased subsidence, separation of rivers from coastal systems by levees, and widespread contamination (Syvitski et al., 2009; Giosan et al., 2014; Tessler et al., 2015; Day et al., 2016; Day et al., 2019; Day et al., 2020).

In this article we consider the future of urban areas focusing on coastal cities, in the cumulative context of the impacts of the global change forcings outlined above. In doing so we address several fundamental 21st century questions. Urban growth over the last two centuries was sustained by abundant cheap energy, overwhelmingly fossil fuels (Burger et al., 2019). At the beginning of the industrial revolution, most large cities were in the temperate zone. However, large cities have increasingly developed in sub-temperate and tropical areas. The growth of cities led to a dramatic demand for goods and service provided by the biophysical base of the earth system (Brown et al., 2014; Steffen et al., 2015; Burger et al., 2019). This has brought about a dramatic degradation of natural systems on which humans depend. Along with dramatic increases in per capita energy use and GDP growth have come bourgeoning greenhouse gas emissions by two orders of magnitude (100-fold) or more as countries urbanized (Burger et al., 2019). A central question, then, is whether climate change in combination with other global trends are so profound that the sustainability of many cities, and especially coastal cities, is questionable. Will the trajectory of the urban transition continue through this century and into the next or will it stall or even reverse?

By addressing these questions, our review responds to the focus of this special issue *Coastal Cities in a Changing Climate*. We turn first to urbanization in the coastal zone, the growth of cities, and the urban transition. Because the focus of the special issue is on climate and coastal cities, we develop a detailed section on global climate change drivers including global warming, tropical cyclones, wildfires (and why this is important for some coastal cities), drought risk and water stress, and extreme precipitation events. We then integrate climate forcings with other megatrends in the context of the Great Acceleration, urbanization and ongoing Anthropocene evolution, including resource scarcity, challenges to the fossil energy-renewable energy transition, urban areas and disease, and food security.

This is not a detailed review of all available literature. We regard coastal cities as being leading indicators of the impacts of global change on urban areas. They are not only useful from the point of view of current trends in coastal cities evolution but also serve to show how long term-climate changes will impact all cities. As such, our selection criteria are focused on variables that most evidently impinge on coastal cities such as sea level and subsidence, increasingly heavy precipitation events resulting from tropical storms, freshwater stress and drought/wildfire dangers. On the social side, we pursue the thermodynamics of international commerce since coastal cities have been at the core of transportation and human population growth for

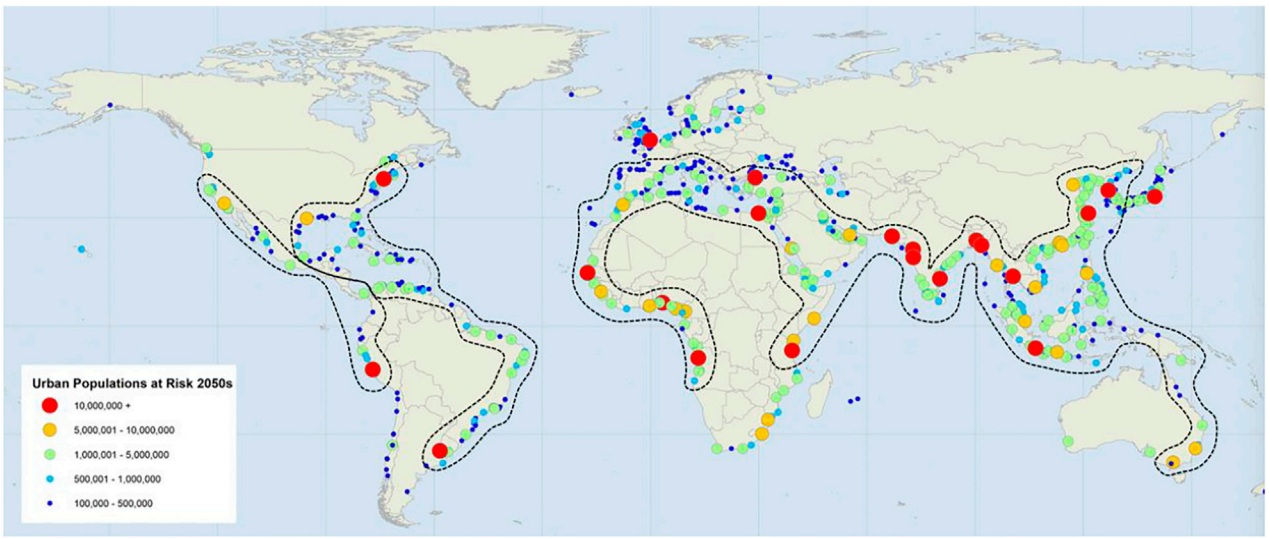

FIGURE 1 | Colored dots show coastal cities that will be significantly impacted by sea-level rise. Note that many of the largest cities are on lower income tropical to sub-temperate coasts (C40.org, 2020). Coastal zones enclosed in the highlighted area will experience multiple climate stresses that will interact with other mega-trends that will lead to diminished resilience and sustainability (Modified from C40 2020. Reprinted by permission).

3,000 years, a tendency certainly not diminished by the current trend towards transportation on the seas to supply megacities. To obtain these measures, we select from key synthesis reviews such as the IPCC, UN population studies, the International Energy Agency and the United States NOAA that encompass key global and social change variable sets that could impact coastal city sustainability.

URBANIZATION IN THE COASTAL ZONE

We provide here more detailed information about growth in population and consumption, the urban transition, and the growth of coastal cities. In 1800, there were only two cities in the world with a million inhabitants. By 2018, there were about 550 cities of a million or more and by 2030 it is projected that there will be over 700 such cities. One in five people globally lives in cities with more than a million inhabitants. In 2010, there were 33 cities of 10 million inhabitants, the megacities, and by 2030 it is projected that that there will be 43. Only one of the top ten megacities in 2030 will be in a developed country (Tokyo).

Much of the growth of urban areas is happening in the coastal zone, especially between 30° north and south, which is home to more than 60% of the 33 largest megacities worldwide (see **Figure 1**, https://digitallibrary.un.org/record/3799524). **Figure 1** shows coastal cities that will be increasingly impacted by sea level rise, especially after the mid 21st century. Oppenheimer et al. (2019) and IPCC (2019) reported projections of sea-level rise from 1986–2005 to 2081–2100 (values in parentheses are in meters, ranges are in brackets) (0.43 [0.29–0.59] for RPC2.6, 0.55 [0.39–0.72] for RPC4.5, and 0. 84 [0.61–1.10] for RCP 8.5). Note that most of the cities in **Figure 1** are in sub-temperate to tropical areas in less developed countries. In addition to sea-level rise, these cities will face the above variety of other climate forcings, which we will now review.

GLOBAL CLIMATE CHANGE DRIVERS

As mentioned above, climate change impacts are affecting the biogeosphere and society globally and coastal areas are at the forefront of the climate change experience of increasing temperature, sea-level rise, tropical cyclones, drought and water stress, wildfires, and extreme precipitation events (Goldenberg et al., 2001; Emanuel, 2005; Webster et al., 2005; Hoyos et al., 2006; FitzGerald et al., 2008; Pfeffer et al., 2008; Vermeer and Rahmstorf, 2009; Kaufmann et al., 2011; Min et al., 2011; Pall et al., 2011; IPCC, 2013; Horton et al., 2014; Mei et al., 2015; DeConto and Pollard, 2016; Koop et al. 2016). Added to global warming will be increasing energy costs leading to higher economic costs for energy-intensive activities to address climate threats (Tessler et al., 2015; Wiegman et al., 2017 as addressed below).

Temperature. Extreme heat is affecting increasingly larger areas of the globe. For example, Stott et al. (2004) reported that human activity was largely responsible for the European heat wave of 2003 (**Figure 2**). Xu et al. (2020) found that for the last six millennia of the Holocene, human populations occupied a relatively narrow part of the global climate envelope and production of crops and livestock was largely constrained to the same temperature range. The position of this climate envelope is projected to shift more in the next half century than it did in the past 6,000 years (**Figure 3**). Xu et al. conclude that a third of the human population will experience a mean annual temperature greater than 29°C by 2070, compared to 11–15°C for the past six millennia. The most dramatic reduction of temperature suitability is projected to occur in the tropics, subtropics and

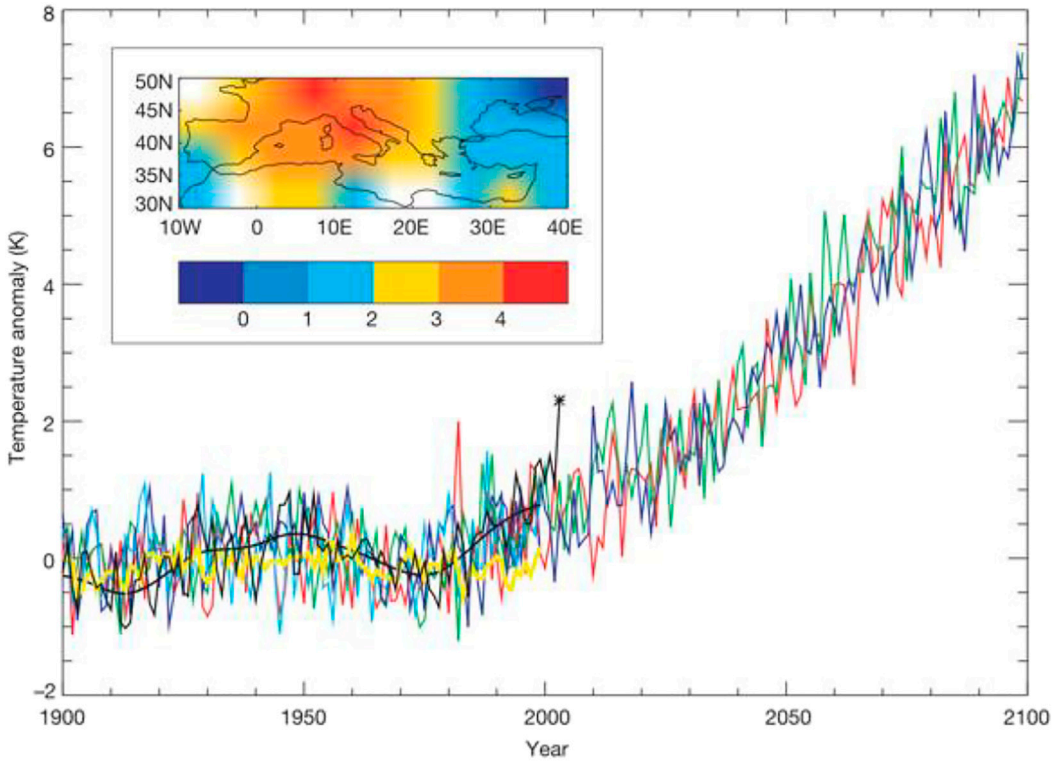

FIGURE 2 | June–August temperature anomalies relative to the 1961–1900 mean for Europe (inset). Black line is observed temperatures and heavy black line is a low pass filtered temperature. Colors are future modeled temperatures; heavy yellow line is natural forcing. Observed temperature for 2003 is shown as a star (from Stott et al., 2004. Reprinted by permission).

sub-temperate zone, especially along tropical coasts. Mora et al. (2017) also showed that projected climate change will lead to temperatures that exceed human thermoregulatory capacity and that 30% of the world's population is already currently exposed to lethal temperature-humidity conditions (**Figure 4**). This is exacerbated by urban "heat-island" affects in humid coastal cities. By 2100, they projected that this percentage would increase from approximately 48–74% depending on future emissions. They further concluded that mortality from high heat is almost inevitable and will be much worse without reductions in greenhouse gas emissions. The use of non-metabolic energy to mitigate high temperatures through air-conditioning is less accessible in the lower-income tropics than in high-income countries (e.g., Hill et al., 2013).

Figure 5 shows that lethal heat waves are becoming more common globally. Based on tree ring reconstructions of heatwaves and soil moisture over the past 260 years, Zhang et al. (2020) documented an abrupt shift to a hotter and drier climate over inner East Asia that they described as crossing a tipping point. Over the past 2 decades, the East Asian climate system trend exceeds the natural variability range for this region that is potentially irreversible. If realized, it will impact the large populations in coastal areas of southeast Asia. Increasing heat waves will also pose challenges for food security, especially in low-income countries in the tropical belt (see below). Extreme heat will also impact wild and domestic food production and storage (Hammond et al., 2015), especially in coastal zones where livelihoods are often dependent on local and regional harvest and trade. This is discussed in more detail below.

The oceans are warming also. Oliver et al. (2021) reviewed prevalence of marine heatwaves that can be detected more accurately and easily by satellite observations. Global climate change has led to an increase in the frequency and duration of marine heatwaves (**Figure 6**). The impact of these heat waves on coastal systems is addressed later in the paper. The increasing frequency of marine heatwaves raises the question of ocean heat absorption capacity. Loeb et al. (2021) reported that the amount of heat stored by the earth system doubled from 2005 to 2021. While the exact global temperature at which the capacity of the oceans to absorb excess heat is not known, this great rate at which it is being used up suggests a rapidly approaching tipping point that will substantially and irreversibly change the locations of the human climate envelope.

Sea-Level Rise. Eustatic sea-level rise is projected to increase by up to 1 m by 2100 and maybe more. It will increasingly impact coastal areas in this century. Especially vulnerable are coastal regions with large areas of near-sea level land (**Figures 1**, **7**). Most important will be large deltas that are concentrated in the tropics and subtropics (Syvitski et al., 2009; Giosan et al., 2014; Day et al., 2016; Day et al., 2019). A number of megacities are located bordering on or in deltas (Yangon, Kolkata, Dhaka, Ho Chi Minh City, Shanghai, Cairo, Karachi, Lagos). Changes in the drainage basins of large deltas

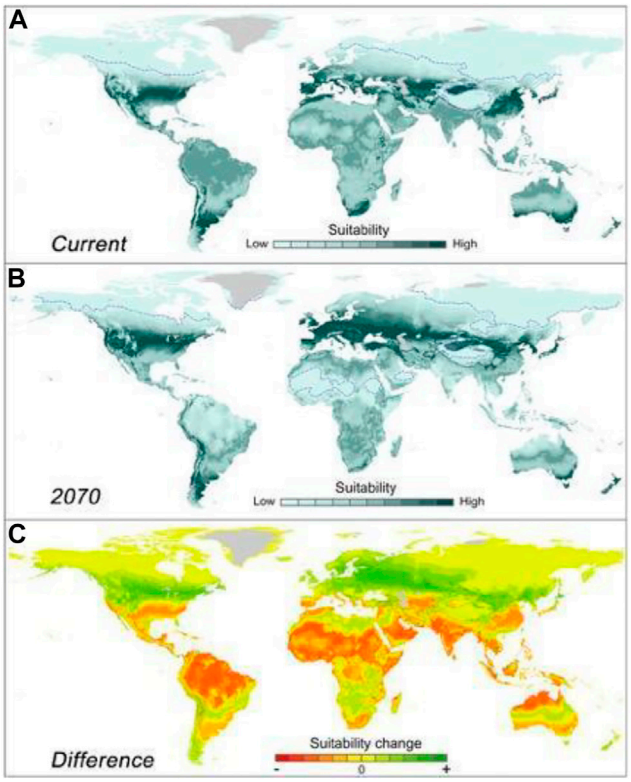

FIGURE 3 | Projected geographical shift in the human temperature niche in terms of the suitability for human habitation. Large areas of the earth will have significantly lower suitability in terms of temperature, especially in the tropics and subtropics. Top panel. Current position of the human temperature niche. Mid panel. Change projected for 2070 with RCP8.5. Bottom panel. Bottom panel. Differences between the two maps. (Xu et al., 2020. Reprinted by permission).

(freshwater withdrawal, sediment retention behind dams) and local changes (reclamation, hydrologic alteration) are decreasing the resilience of these areas (Giosan et al., 2014; Tessler et al., 2015; Day et al., 2016; Day et al., 2019). High subsidence rates are frequent due to geologic subsidence in deltas (due to compaction and consolidation of sediments) that lead to high rates of relative sea-level rise (subsidence plus eustatic sea-level rise). Subsidence is also caused by subsurface fluid withdrawal (Day et al., 2019). Sea-level rise can interact with ocean circulation to exacerbate coastal flooding and saltwater intrusion (Wahl et al., 2015; Lee and MingZhang. 2017; Pietrafesa et al., 2019).

Tropical Cyclones. Increasing warming of ocean surface waters has amplified the impacts of tropical cyclones. Emanuel (2005) reported that a 1°C increase in sea surface temperature in the tropics over the past half century generated approximately 80% increase in hurricane intensity or power. It has been reported that the frequency of the most intense tropical storms is increasing (Webster et al., 2005; Hoyos et al., 2006; Elsner et al., 2008; Bender et al., 2010). Mei et al. (2015) predicted climate change will increase already high average typhoon intensity in the Pacific area by 14% by 2100. Tropical cyclones are also intensifying more rapidly (Bhatia et al., 2019) as are large surge events (Grinsted et al., 2012). Li and Charkraborty (2020) analyzed the intensity of North Atlantic landfalling hurricanes over the last 50 years and found that the rate of decline in hurricane strength over land has decreased in inverse proportion to the rise in sea surface temperature causing greater flooding concerns in coastal and inland cities. Tropical cyclones impact the western basins of the north Atlantic and North Pacific, the northern part of the Indian Ocean, and parts of east Africa and Australia (**Figure 8**). Countries bordering the western Pacific and Indian Ocean are among the most populous and highest human population densities in the world (Burger et al., 2017; Burger and Fristoe 2018; Burger et al., 2019). This area contains many coastal megacities (**Figure 1**). In summary, it is projected that the frequency of the strongest tropical cyclones will increase, and these storms will be larger, intensify faster, have more precipitation, intensify faster, move slower, and decay more slowly over land.

Wildfires. Wildfires are becoming more frequent, covering larger areas, and wildfire seasons are becoming longer. Robinne et al. (2020) analyzed global wildfire-water risks to human and natural systems using a global index to assess wildfire risk. Large, intense wildfires have occurred on the west coast and

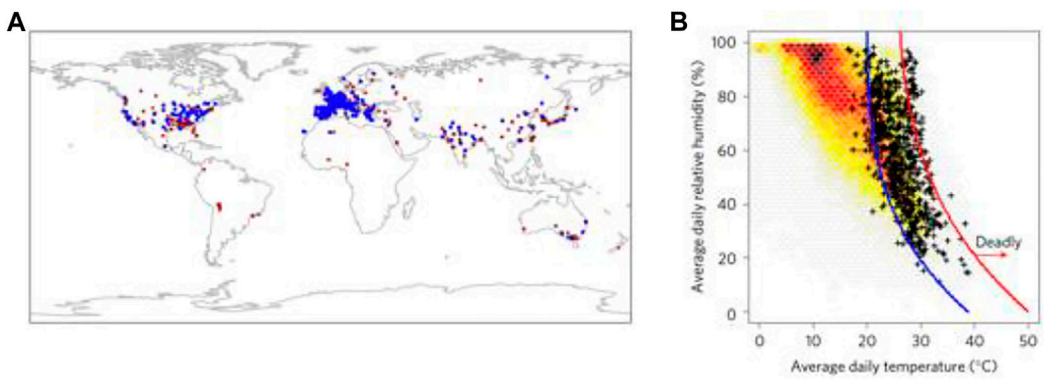

FIGURE 4 | (A) Locations of recent recorded lethal heat events. **(B)** Mean daily surface air temperature and relative humidity during lethal heat events (black crosses) compared to non-lethal events (red to yellow). Blue line separates lethal and non-lethal events and red line is 95% probability threshold for lethal events (from Mora et al., 2017. Reprinted by permission).

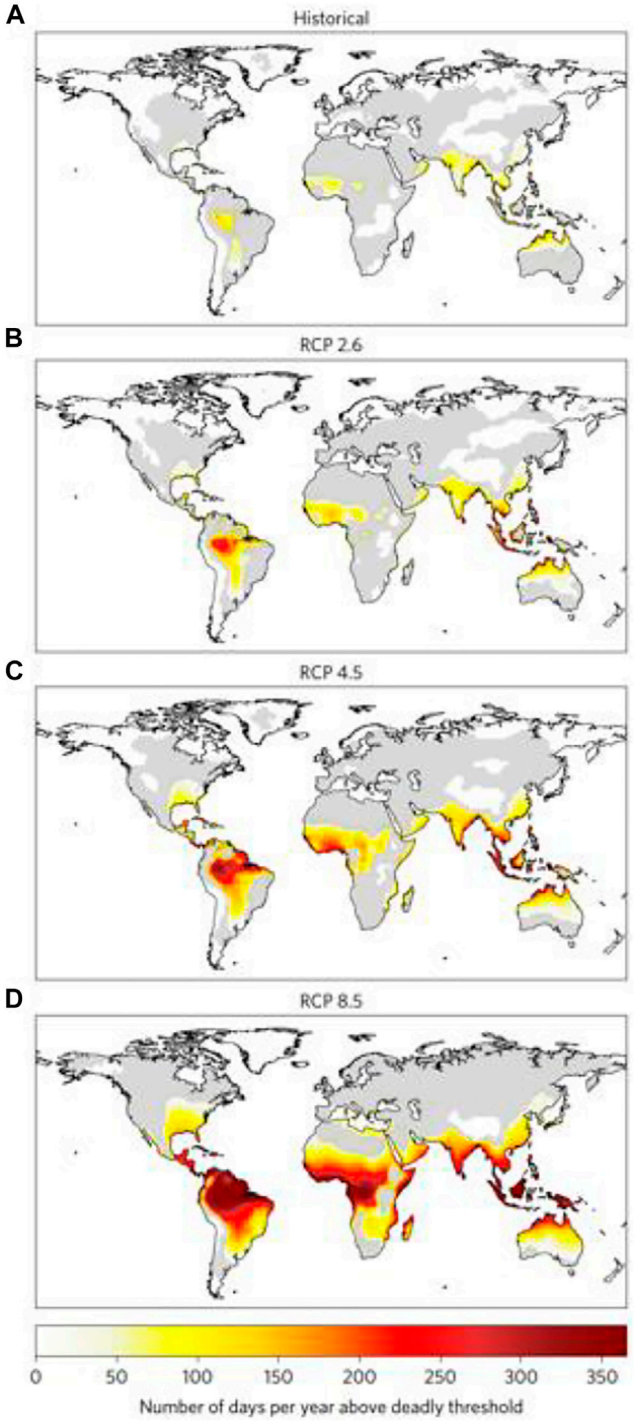

FIGURE 5 | Global patters of the number of days per year above deadly threshold (to the left of the blue Line in **Figure 4B**) for 1995–2005 average and for different emission scenarios. From Mora et al. (2017). Reprinted by permission.

southwestern United States, Greece, Indonesia, Australia, central Chile, Amazona, and other areas in recent years. Wildfire risks can be particularly acute in water-insecure countries. Wildfire-induced risk is higher in low-income countries because of the lack of socio-economic capacity to respond to disasters (e.g., Dyer, 2009; Tessler et al., 2015). The wildfire-water index is high along the northern and southeastern coasts of Australia, the Philippines, the Indo-Pacific area, coastal northwestern Pacific, the Asian and east African coasts of the Indian Ocean, Mideast and Mediterranean coasts, western Europe from Spain to Scandinavia, tropical west Africa, the Atlantic, Gulf and Pacific coasts of North America, and Central America, and much of South America (**Figure 9**).

Although not a coast-specific climate forcing, wildfires can strongly impact coastal cities. Fires can directly threaten coastal cities such as Los Angeles and Sydney and they create extremely poor air quality. Wildfires are more common in arid areas and combine with drought to reduce the sustainability of coastal cities. An example is the coastal region of California. The Los Angeles-San Diego area is the second largest ex-urban area in the United States. This region obtains water from northern California, the Colorado River and Owens Valley, Nevada. Projections are for increasingly arid conditions in the Southwest, lower river discharge, and greater water demand (Ingram and Malamud-Roam, 2013; Milly and Dunne, 2020; Williams et al., 2020). Thus wildfires, drought, and water scarcity can combine with coastal climate forcings such as tropical cyclones and sea level rise to threaten the sustainability of coastal cities. The impact of these forcings may in part contribute to the current population decline in California.

Drought Risk and Water Stress. Climate change and human water demand is leading to more intense droughts (United Nations, Department of Economic and Social Affairs, Population Division., 2018). Global drought risk and water stress are related. These are especially intense and widespread around the Mediterranean, temperate forests, along the northern shore of the Indian Ocean, Middle East, and southeast Asia, and the American Southwest and much of southern Mexico and Mesoamerica, southeastern South America, and tropical west Africa (**Figure 10**).

Extreme Precipitation. Extreme precipitation events are becoming more common worldwide (Schiermeier, 2011). Using observations and modeling, Min et al. (2011) showed that human-induced increases in greenhouse gases have contributed to observed intensification of heavy precipitation events over a large part of northern hemisphere land areas (**Figure 11**). Pall et al. (2011) used modeling to evaluate the impacts of climate warming and concluded that in nine out of ten cases model results indicated that 20th century anthropogenic greenhouse gas emissions increased the risk of floods occurring in England and Wales in the autumn of 2000 by more than 20%. In two out of three cases by more than 90%. An example of an extreme, intense precipitation event is Hurricane Harvey, which in 2017 led to a total rainfall of about 1.5 m in three days when the hurricane became semi-stationary along the south Texas coast (**Figure 12**).

The information presented here shows that current and future climate forcings will affect almost all of the earth's coasts. A broad zone that includes tropical to sub-temperate regions around the globe will be affected by most of the forcings discussed above

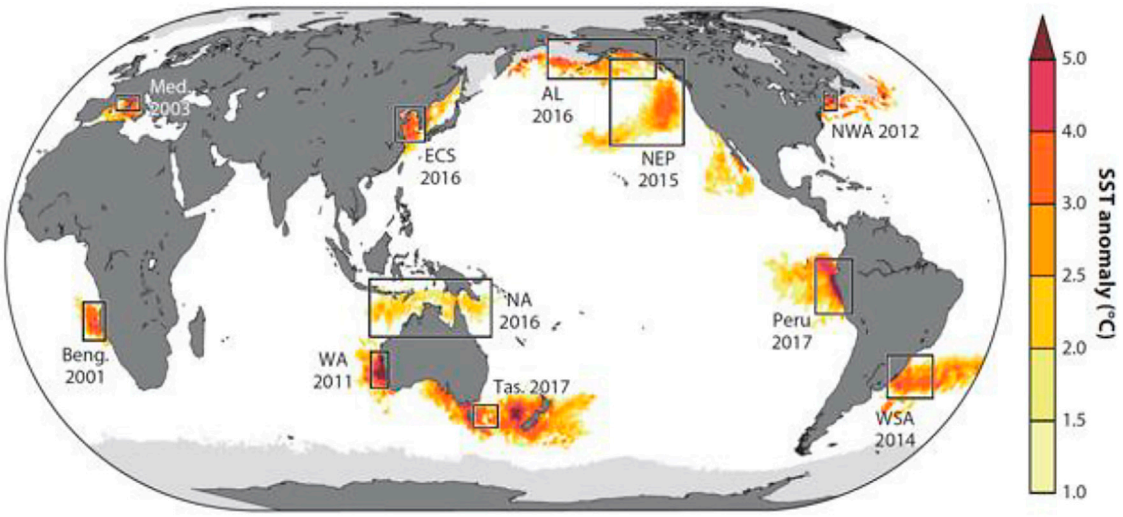

FIGURE 6 | Example of Marine Heatwaves (MWH) since 2001 as indicated by sea surface temperature anomalies. These occur from high latitude to tropical waters. From Oliver et al. (2021). Reprinted by permission.

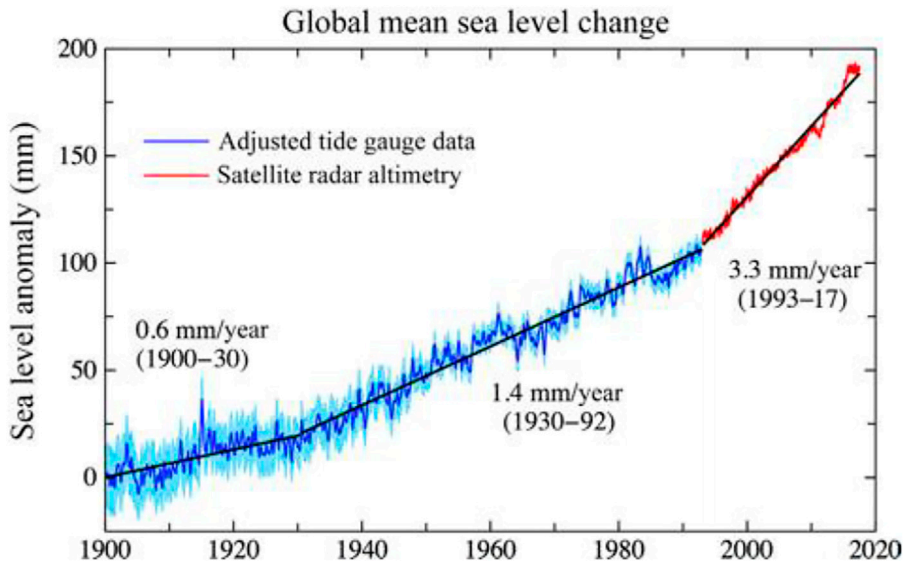

FIGURE 7 | Rates of global sea-level rise from 1900 to 2015 (Hansen et al., 2015. Reprinted by permission).

(**Figure 1**). It includes a large proportion of the world's population, almost all of the world's major deltas, and most coastal megacities. It should be noted that climate change forcings that are not normally considered "coastal" forcings can impact coastal cities. For example, wildfires are becoming more intense and the length of the wildfire season in many areas is increasing. Coastal cities in some areas affected by wildfires that are normally not impacted by coastal climate forcings such as sea level rise or tropical cyclones can become less resilient and sustainable because of global change-fueled forcings such as intensification of wildfires and drought, especially when combined with other global change drivers. Some examples include southern California and northwestern Mexico, the Mediterranean and Middle East, central Chile, and the southeastern coast of Australia.

To directly address the concerns of the special issue on *Coastal Cities in a Changing Climate, we* suggest that climate change alone will threaten the sustainability and resilience of many coastal cities, especially in lower-income countries in the tropical to sub-temperate zone. Indeed, current climate

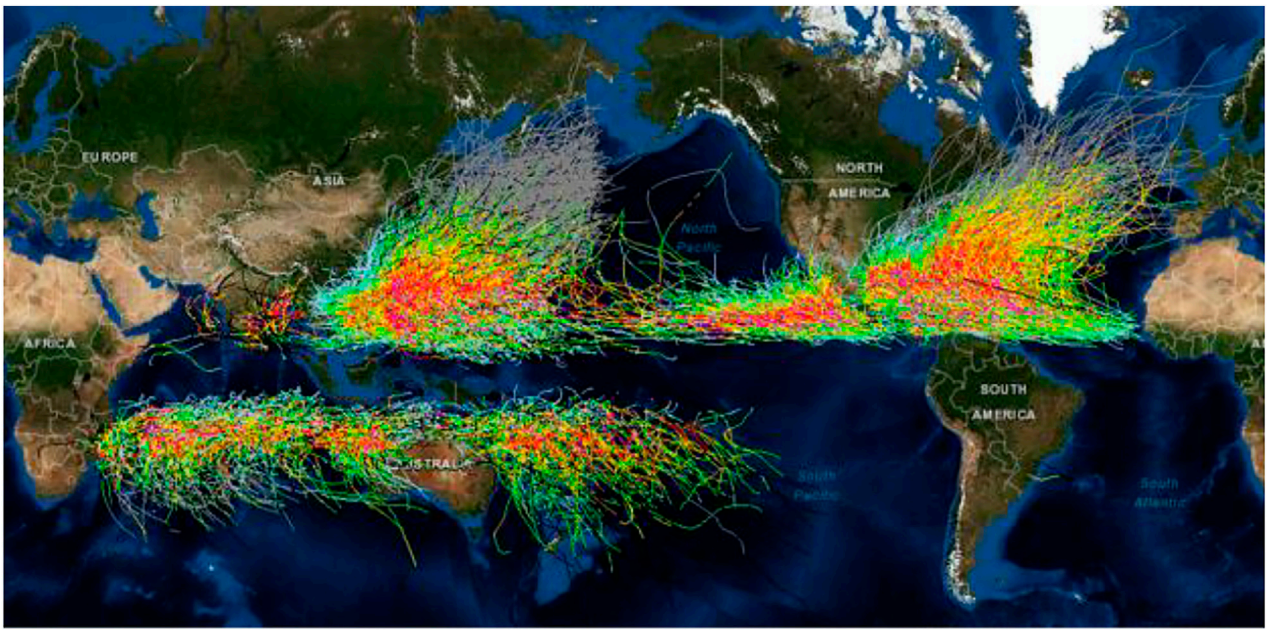

FIGURE 8 | Global tropical storm tracks 1848–2013. Red and orange, Saffir-Simpson category 4 and 5, yellow and green category 1-3, blue tropical storms, and depressions. Source NOAA Digital GeoZone.

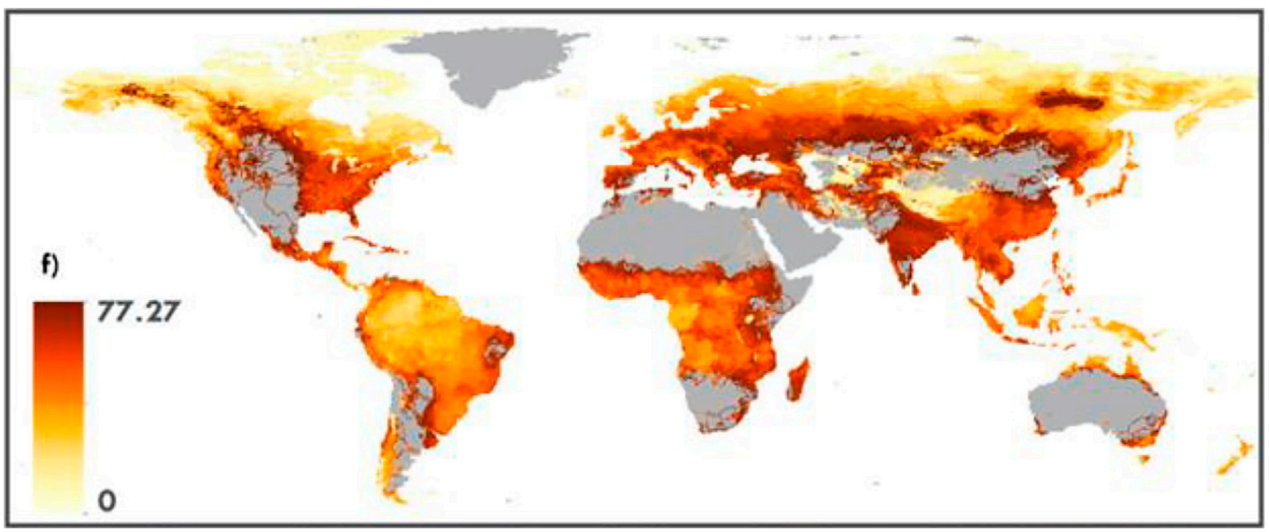

FIGURE 9 | Wildlife-Water Risk index globally. Red areas have higher risks. Areas in gray were excluded from the analysis because of low precipitation and/or runoff–see **Figure 10** for comparison. (Robinne et al., 2020, Reprinted by permission).

impacts are already dramatically impacting coastal cities in advance of more inland cities. However, the nature of cities themselves in combination with other global change forcings suggest that the trend towards further urbanization may become infeasible as this century progresses. Taken together the global change forcings have contributed to a new state of the earth/societal system that has been termed the Anthropocene. We address these issues in following sections.

THE GREAT ACCELERATION, URBANIZATION, AND RESOURCE SCARCITY

Acceleration. Twentieth century science has led to increasing recognition of the impact of human activities on the biogeosphere (Steffen et al., 2011; Steffen et al., 2015). Because of this, there is a growing consensus that earth has entered a new geological epoch

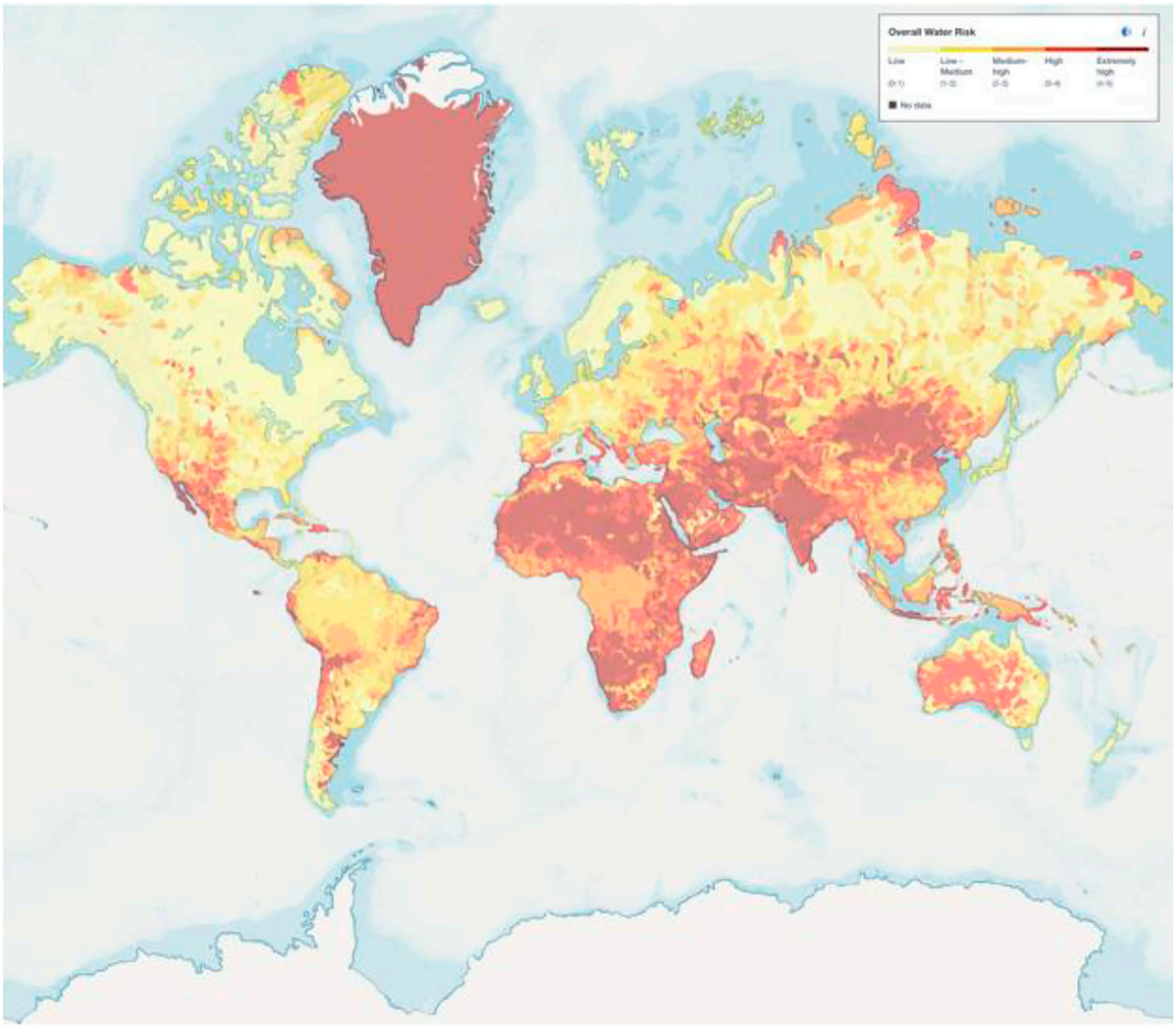

FIGURE 10 | Global drought risk and water stress (https://wri.org/applications/aqueduct/water-risk-atlas/#/?advanced=false&basemap=hydro&indicator=w_awr_def_tot_cat&lat=-8.841651120809145&lng=35.06835937500001&mapMode=view&month=1&opacity=0.5&ponderation=DEF&predefined=false&projection=absolute&scenario=optimistic&scope=baseline&timeScale=annual&year=baseline&zoom=3). Used by permission, copywrite Beta Aqueduct Water Risk Atlas. Creative Commons (creativecommons.org/licenses/by/4.0/#). Use does not imply endorsement by Creative Commons or The Aqueduct.

called the Anthropocene (Crutzen, 2002; Syvitski et al., 2020). This is especially apparent in the second half of the 20th century, the so-called exponential century or Great Acceleration (Steffen et al., 2018). Climate change and related mega-trends such as energy scarcity, population growth, massive resource consumption, and environmental degradation will impact natural and social systems globally, but the impact is being felt earlier and stronger in many coastal systems, especially in lower latitudes (e.g., Poff et al., 2002; Tessler et al., 2015; Day et al., 2018; Day and Rybczyk, 2019). Growing environmental impacts and decreasing energy availability will likely combine to limit options for restoration and management of coastal zones and complicate human response to mitigate climate change affects in coastal cities (Day et al., 2007; Tessler et al., 2015; Day et al., 2016; Wiegman et al., 2017).

Various points of view have developed over the future of the human population. In 2021, global population reached 7.7 billion. The United Nations, Department of Economic and Social Affairs, Population Division, (2019) projects that global population will continue to grow but at a slowing rate through the 21st century and that total population will reach 8.5 billion in 2030, 9.7 billion in 2050, and 10.9 billion by 2100. However, the demographic transition comes at the cost of increasing per capita consumption (Moses and Brown, 2003; DeLong et al., 2010) and may be limited by available resources.

Alternatively, Vollset et al. (2020) modeled future population on purely demographic drivers, fertility, migration, and mortality.

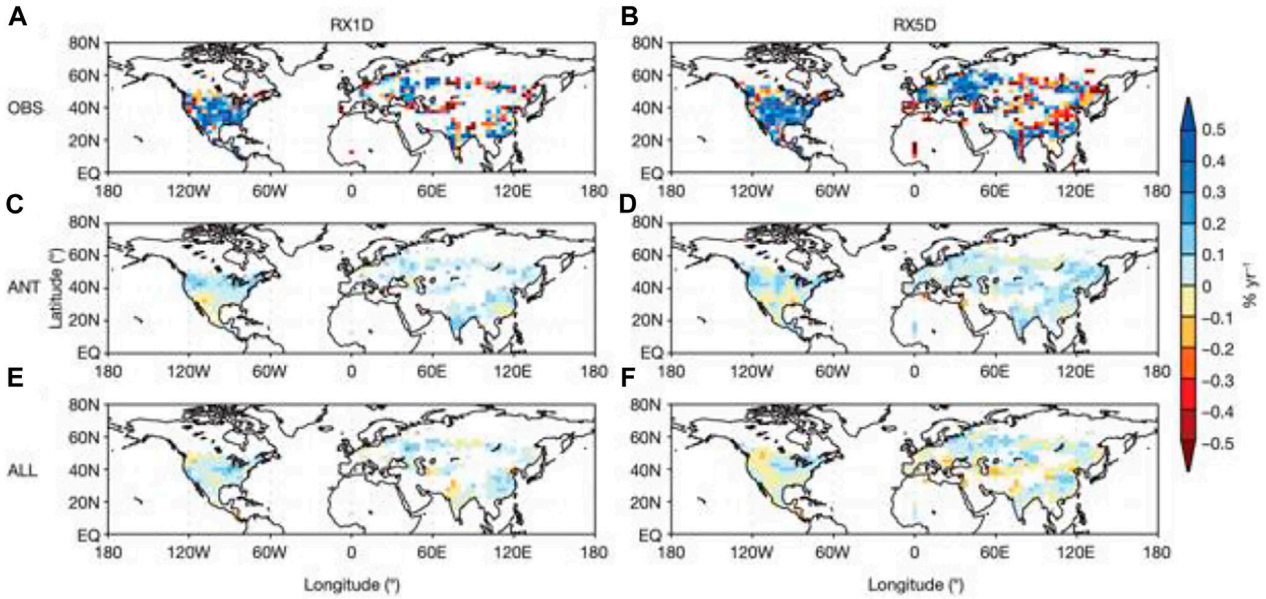

FIGURE 11 | Comparison of geographical trends of extreme precipitation indices for 1951-1999 for annual maximum daily (RX1D) and five-day RX5D) precipitation amounts. **(A, B)** Observations, **(C, D)** model simulations, and **(E, F)** combined for observations (OBS), anthropogenic forcing (ANT), and anthropogenic plus natural forcings (ALL) (from Min et al., 2011, Reprinted by permission).

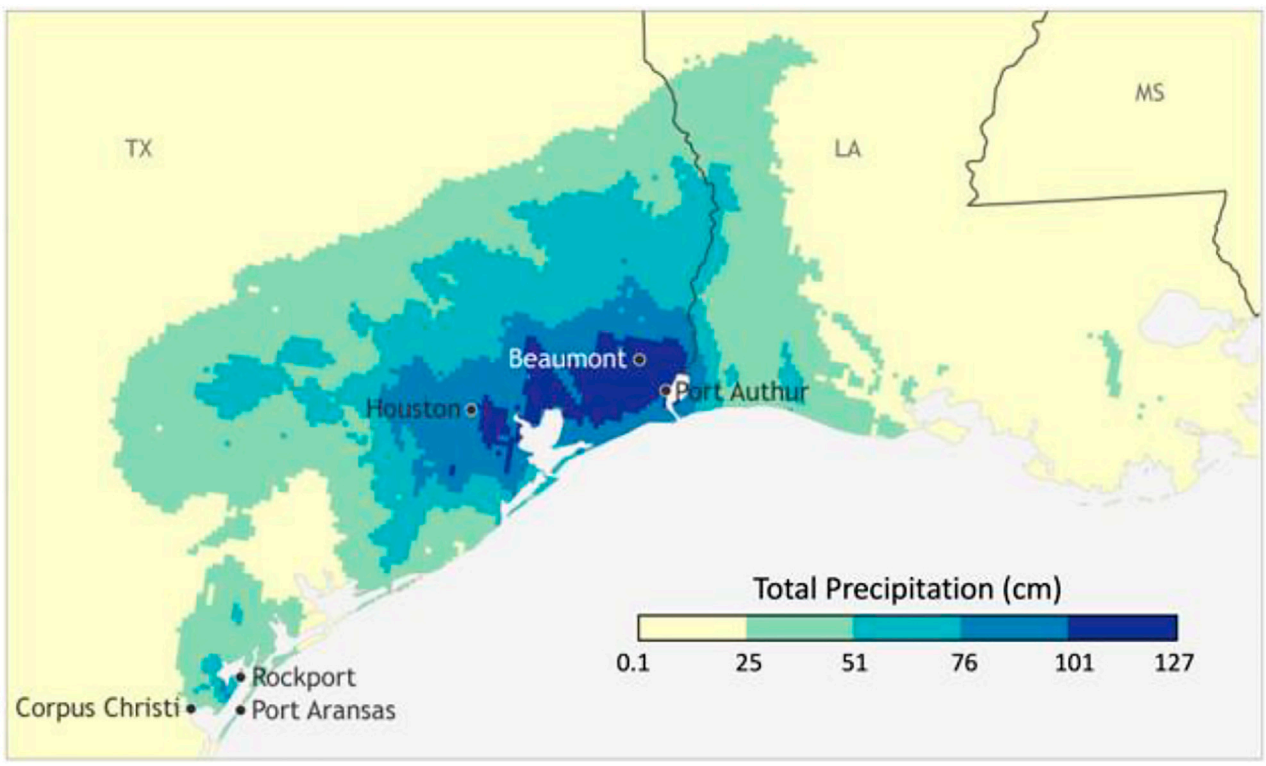

FIGURE 12 | Rainfall during Hurricane Harvey in the Houston vicinity. Peak rainfall was more than 1.5m over three days. (modified from https://www.climate.gov/news-features/event-tracker/reviewing-hurricaneharveys-catastrophic-rain-and-flooding, accessed on 7 January 2021).

He projects that global population will peak at 9.73 billion in 2064 and then a decline to 8.79 billion by 2100. To this can be added other important factors affecting population decline, female educational attainment, access to contraception, and increased per capita energy use that coincides with increased economic development (Moses and Brown, 2003). Thus, such scenarios of populations peaking and declining can be questioned given currently available energy reserves (DeLong et al., 2010; Burger, 2019). In the meantime, the high-income world continues to be the major consumers of fossil fuels, renewable biocapacity and contributor of greenhouse gases, all of which could attenuate the advance toward population peaking.

Urbanization. As noted above, an important defining characteristic of urbanization is the global urban transition. This occurred around 2010 when the proportion of the world's population living in urban areas exceeded 50% and coincided with dramatic growth of megacities. This is fundamentally different from the way that our species lived for almost the entire period it has existed (about 300,000 years; Burger et al., 2017; Burger and Fristoe, 2018). As noted above, since 1800 the global population has grown by about 7.5 times while the growth of cities of more than a million people has grown by a factor of more than 500. In the mid-1800's England was the first country to go through the urban transition. The urban transition has been interpreted as an encouraging sign that the human population and economy are on a path toward greater global sustainability according to some authors (e.g., Jenks and Burgess, 2000; Newman, 2006; Glaeser, 2011; Rose, 2016) who have suggested that concentrating the Earth's growing population and industrial-technological-information economy in urban centers will reduce human impacts on the environment by packing more people in efficient cites.

However, this is likely not the case because modern megacities are dependent on energy and material flows from ex-urban environments globally (Rees and Wackernagel, 1996; Poumanyvong and Kaneko, 2010; Burger et al., 2012; Rees, 2012; Burger et al., 2017; Burger et al., 2019; Schramski et al., 2015; Baabou et al., 2017; Isman et al., 2018). It has been shown that per capita GDP is related to per capita energy use (Odum, 1971; Brown et al., 2011; Brown et al., 2014; Hall and Klitgaard, 2017). Brown et al. (2011), Brown et al. (2014), and Schramski et al. (2015) and others have concluded that the current economic paradigm based on increasing human population, economic development, and standard of living is no longer compatible with the biophysical limits of a finite Earth. The continuing global economic failure to maintain past growth rates is due to scarcity of critical resources including oil, gas, water, arable land (especially soil carbon and other depleting nutrients), metals, rare earths, fertilizers, fisheries, and wood (Burger et al., 2012). As the modern industrial-technological-informational-economy expanded and urbanization increased over the 20th century, it grew by consuming the Earth's natural resources at unsustainable rates. Correlations between per capita GDP and per capita consumption of energy and other resources across nations and over time demonstrate how economic growth and development depend on the capital of natural resources or ecosystem services as well as cheap energy. There has been a decades-long trend of decreasing per capita consumption of multiple important commodities that indicate that this overexploitation has created an unsustainable bubble of population and economy (Burger et al., 2012). Portland Oregon is illustrative of the problem of the "green" city. Burger et al. (2012) reported that Portland, in spite of its reputation, used vast quantities of gasoline, natural gas, electricity, water, food, and other resources and released large amounts of liquid sewage, CO_2, and solid waste. Domestic and international trade involved millions of tons annually. With respect to these flows, they concluded green Portland was about average for a United States city of comparable size with respect to the flows mentioned.

Energy. Per capita energy use and per capita greenhouse gas emissions in different countries varies by over two orders of magnitude and is related to the degree of urbanization (Burger et al., 2019). Energy use per capita is about 500 W in the poorest countries, barely more than the 100 W of human biological metabolism. In the richest countries, it is more than 10,000 W because human metabolism has been supplemented more than 100-fold from exogenous, ex-urban energy sources, mostly fossil fuels as well as enormous resources extracted from the biogeosphere. Data on a variety of variables that reflect standard of living and quality of life (Brown et al., 2014), including indices such as the human development index, wealth and poverty, infant mortality, food consumption, ownership patterns, education, and research spending, are strongly related to per capita GDP, which is strongly related to per capita energy consumption.

Two central questions relative to this dilemma is whether renewable energy can be ramped up fast enough to replace fossil fuel decline (due either to depletion of economically viable fossil fuel reserves or to conscious decisions to reduce fossil fuel use to avoid climate impacts) and the degree that renewables can replace all important uses of fossil fuels such as heavy industry, transportation, and food production (Smil, 2017; Day et al., 2018; EIA(Energy Information Agency), 2019; IEA(International Energy Agency) 2020; Smil, 2021).

To avoid temperature increases greater than 2 C, fossil fuels must be largely phased out by 2050 (IPCC, 2019; Oppenheimer et al., 2019). The IEA(International Energy Agency). (2020) reported that global reliance on fossil fuels decreased from 95% of total primary energy in 1975 to about 85% in 2020. They project that 70–75% of global primary energy consumption may be met *via* fossil fuels in 2040. If new renewables are to replace fossil fuels by mid-century, they must increase by more than 10-fold in 3 decades. It took total fossil fuel growth 77 years to increase by a factor of 10 to reach 2010 levels (Maggio and Caddiola, 2012). Thus, to meet fossil fuel phase out by 2050, new renewables growth must be much faster than fossil fuel growth in the 20th century.

As noted above, per capita GDP, per capita energy use and per capita greenhouse gas emissions for most countries of the world increased as the level of urbanization increased (Burger et al., 2019). In all high-income countries, the proportion of the population living in urban areas is greater than 80%. As the proportion of the urban population increases in countries as they go through the urban transition, so does GDP (Burger et al., 2019). The increase is dramatic with per capita GDP, energy consumption and greenhouse gas emissions increasing by 100 to

1,000 fold (2–3 orders of magnitude) from the poorest and least urbanized nations to the richest and most urbanized nations.

It has been argued that the shift to a service economy results in lower per capita energy consumption because by shifting from producing goods to providing services, a society can reduce consumption and result in lower per capita energy use (Hawken et al., 2000; –See Heiskanen and Jalas, 2000; Heiskanen et al., 2001; Romm, 2002; Victor, 2010 for reviews). Direct energy intensity of value added and direct energy use per worker are significantly lower for services compared to industry for the United States. However, Fix (2019) showed that fossil fuel use per capita and CO_2 emissions per capita were significantly and positively related to the percent of the population in the service sector. This is consistent with the findings of Burger et al. (2019) showing increasing per capita energy use and greenhouse gas emissions and that the service sector accounted for a greater proportion of the economy with increasing urbanization.

Urban Areas and Disease. Urbanization complicates global health and facilitates epidemics of infectious diseases (Neiderud, 2015). With the rapid urbanization that has taken place over the past century, rural areas can become incubators for epidemics that can spread more rapidly to cities *via* global transportation, becoming worldwide threats. The current COVID-19 pandemic is an illustrative example. Among different cities and within individual cities, there can be very different levels of social security and access to modern health care, as for example the differences between slums and wealthy neighborhoods. The former are often very crowded and lack access to freshwater and sanitation facilities. Thus, the hyper-densities of modern cities (Burger et al., 2017) can be catalysts for rapid spread of infectious diseases due to such factors as tourism and international trade.

As noted, the conditions leading to the spread of infectious, as well as lifestyle diseases, are common in cities in poorer countries. This is exacerbated in cities in coastal areas in tropical and subtropical areas where much urban growth is taking place. An interesting case study is the ancient civilization of the Maya culture that progressed its urbanization from villages in southern lowland swamps 3,000 years ago, to magnificent templed cities on promontories by 1,500 years ago. This was followed by the famous Maya collapse, but the collapse was actually only of the interior cities. Coastal cities then moved to the fore of commerce by capitalizing on the efficiency of maritime transportation. The lesson to be learned was/is that large, dense urban populations cannot sustain themselves in challenging tropical environments where they are highly susceptible to pandemics. Rather they had to be installed on high terrain, in porous substrates to avoid water contamination and enable annual flushing of the cities by rains. This however unexpectedly exposed them to extended droughts in the AD 800's that diminished their sustaining clean water resource, equivalent to our singular reliance on fossil energy of today's society (Scarborough et al., 2012; Gunn et al., 2019a; Gunn et al., 2019b).

Food security. Both climate change and resource scarcity will have consequences for food security. We are already seeing the effects of extreme heat waves on food production. Schramski et al. (2019) discussed future trends affecting the sustainability of food self-sufficiency. The ability to feed the world's growing population over the past century and a half depended on decreasing food loses, increasing food yields, and cheap fossil fuels and transportation networks to distribute food globally (Hammond et al., 2015). Food self-sufficiency at the country level has been declining over the last 4 decades as the number of countries able to provide sufficient local food declines. Food imports have been able to offset most of the country declines. This is based on cheap fossil fuels and technological advances in a mechanized food production system with a high level of food preservation. Schramski et al. (2019) argue that global changes in climate, energy availability and other factors will lead to challenges in providing sufficient food for a growing urban population. As discussed earlier, Xu et al. (2020) reported that the narrowing range of the global climate envelope that supports life will impact production of crops and livestock as well as human health. Australia for example, is already experiencing mass die-offs in marine and terrestrial environments due to increasing heatwaves (Ruthrof et al., 2018).

Marine heatwaves also pose a threat to marine fisheries and coastal economic livelihoods. An example is the impact of the 2013–2016 marine heatwave in the northeast Pacific. Cheung and Frolicher (2020) reported that modeling studies indicate that the heatwave caused biomass decreases and shifts in biogeography of northeast Pacific fish stocks. The heatwave has increased the likelihood of harmful algal blooms, shifted distributions of marine life, and changed food webs. Barbeaux et al. (2020) reported that the heatwave led to shifts in species distribution and reduced productivity of Pacific cod in the Gulf of Alaska. The 2013–2015 heat wave increased algal toxins in shellfish and led to the closure of the Dungeness crab fishery.

The global change impacts discussed above have disproportionate impacts on low-income countries. For example, Tessler et al. (2015) reported that combined changes in land use, regional water management, subsidence, climate change, and increasing energy costs will increase risks significantly resulting in non-sustainable outcomes for deltaic coasts. Although both developed and developing countries are exposed to risks, high-income countries presently limit their risk by expensive and energy-intensive infrastructure and coastal defenses. In a world characterized by increasingly scarce and expensive energy, maintaining and repairing such infrastructure will likely become unsustainable. More generally, the impacts of climate change in combination with other global change forcings will fall disproportionately on lesser developed countries, especially large cities in the coastal areas, which are more at risk from climate change. Local and regional food insecurity may additionally be exacerbated by more frequent and longer heat-waves that can impact fisheries and marine resource populations.

SUMMARY AND CONCLUSIONS

Urbanization by the human species started 5,000 years ago worldwide and in the 21st century is rapidly expanding at an unprecedented pace surpassing 50% around 2010. Urbanization is occurring most rapidly in the tropical and sub-tropical zones and in coastal areas, so they represent a potential view of the

future of urbanization as a whole. Climate change in conjunction with other global change impacts will likely diminish the sustainability of cities, especially in coastal areas of low-income countries. Climate change impacts include sea-level rise, temperature increase, increasing frequency of the most intense tropical cyclones, changes in freshwater input to coastal zones, and increasingly severe extreme precipitation events, droughts, freshwater shortages, heat waves, and wildfires. Climate change alone will diminish the sustainability and resilience of coastal cities, but combined with other global changes, this suite of forcings represent an existential threat to coastal cities. Urbanization has brought about two orders-of-magnitude (100-fold) increases in per capita GDP, energy use and greenhouse gas emissions, which in turn has led to unprecedented demand for natural resources and degradation of natural systems that provide these resources (Burger et al., 2019). The urban transition coincides with the Great Acceleration of the Anthropocene, both of which reflect the vastly increased use of energy, principally fossil fuels. These energy sources enabled and underwrote the dramatic expansion of the urban age and fueled the Great Acceleration. It is questionable whether renewable energy can ramp up fast enough to fuel further urban growth, reverse climate change, and minimize further environmental degradation. Continuing the trend toward urbanization is questionable given these trajectories, especially in vulnerable low-income cities in coastal zones in the tropical belt.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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Engineering an Ecological Civilization Along Shanghai's Main Waterfront and Coastline: Evaluating Ongoing Efforts to Construct an Urban Eco-Network

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Recent ecological civilization policies make clear that China is willing to play a leading role in a sustainable green transition. But there are still discrepancies in definitions, appreciation and evaluation of ecological assets. This paper examines how Shanghai works on a sustainability transition, with a focus on its main urban waterfronts and coastline, in the context of an extremely high population concentration, world's highest real estate values, and continuous urban development pressure. This paper will mobilize insights from the academic field of sustainability transitions to show how urban planning and design ambitions are translated into realities on the ground. In its latest Shanghai Master Plan (2017-2035), the city commits itself to set an example for other Chinese cities. Moreover, Shanghai's city leaders want to inspire and push cities internationally to become more adaptable and resilient, both in the Global South and Global North. The spatially most radical action to realize this ambition is to create "a green and open eco-network" with 60% of Shanghai's municipal territory to be used for ecological purposes, mostly wetlands. This paper will examine three urban planning and design projects that have key positions within this eco-network. On all three sites there are land-use conflicts, between urban development and ecological (re-)development. The first case is the recent transformation of no less than 120 km of former industrial dominated waterfront along the Huangpu River, of which half was completed between 2016 and 2021. The second case, Nanhui Coastal Wetland Reserve with adjacent Lingang New City; and the third case, Chongming Eco-Island, started both around the millennium and had a 2020 planning horizon. After learning lessons from their previous sustainable innovation journeys these latter two projects entered a new phase as part of the eco-network. The paper concludes with seven practical recommendations aimed to reduce discrepancies between expectations and their implementation in practice: 1) use clear definitions; 2) co-create a shared vision for the future; 3) stop building on vulnerable locations; 4) create conditions of social learning; 5) supervision needs to go beyond planning boundaries; 6) step beyond an anthropocentric approach; and 7) foster a more experimental approach.

Keywords: ecological civilization, governance, land reclamation, low-carbon transitions, wetlands, urban delta, ecological restoration, sustainability transitions

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INTRODUCTION

China's Shift to a Green Economy and the "War on Pollution"

This paper explains and examines the ongoing transformation of Shanghai's main waterfronts in the context of a new eco-network, informed by sustainability transitions scholarship (Markard et al., 2012) and additional insights from ecological civilization philosophies (Hansen et al., 2018). The paper focuses on the Direct Controlled Municipality[1] of Shanghai, because this region has an exemplary role within China in terms of testing and implementing new policies. Many city leaders see Shanghai as inspiring model, and gateway to the world with access to new ideas.

China's extremely rapid shift to urbanization this century (Hsing, 2010) resulted in prosperity and high living standards for many, but also brought collateral damage, including serious environmental pollution, declining available land and resources, and socio-economic discrepancies (Brown, 1995; Li and Shapiro, 2020; Zhao et al., 2006). Since the beginning of this century, China's policies gradually focused on the new principle of a Green Economy (Linster and Yang, 2018), which essentially turns away from the (western) idea of industrialization. Since it's eleventh Five-Year Plan (2006-2010), the People's Republic of China has committed itself to achieving a Green Economy, aimed at increasing the use of renewable energy sources, drastically reducing carbon emissions, and increasing green coverage of lands. In the twelfth Five-Year Plan (2011-2015) additional targets were added, including reversing ecological deterioration and enhancing environmental regulatory institutions. In March 2014 China declared a "war on pollution"[2] and started to introduce multiple green policies. China's thirteenth Five-Year Plan (2016-2020)[3] continued the lines of the previous two plans and additionally emphasized ecological restoration and protection. This year, on March 11, 2021, China's National People's Congress voted to pass the resolution on the fourteenth Five-Year Plan (2021-2025) and the 2035 long-term goal outline.[4] This plan set 18% reduction of CO_2 emissions and 13.5% of energy-intensity reduction as goals for the coming 5 years. Previous Five-Year Plans showed a trend of largely over-achieving previous set goals, and according to some observers this will likely happen again.[5]

Toward an Ecological Civilization

China is demonstrating its intentions to promote Sustainable Development Goals (UN Habitat, 2015). A key driver in this aspiration is to strive to realize an ecological civilization by 2030 (Hansen et al., 2018). Ecological civilization (生态文明) can be defined as "a dynamic equilibrium state where humans and nature interact and function harmoniously" (Frazier et al., 2019). It is a socio-technical experiment. Although some scholars claim that ecological civilization originates from the western discourses on ecological modernization (Zhang et al., 2007), it has deep roots in Marxism and the potential to challenge and even replace global capitalism (Pan, 2006; Gare, 2020). It has received skeptical reactions from several international observers (Wang et al., 2014; Hansen and Liu, 2017; Wang-Kaeding, 2018). The concept of ecological civilization has been gradually integrated in the policies of the Chinese Communist Party since the 17th National Party Congress in October 2007, when it became a national strategy, as declared by General Secretary Hu[6]: "Towards a new era of ecological civilization to realize the greatness of the Chinese Nation," and "ecological civilization is the key to realize the great renaissance." In 2012, ecological civilization was included in the Party's constitution. Five years later, during the 19th Party Congress, General Secretary Xi Jinping emphasized the need to speed up realizing an ecological civilization and a more balanced model of economic growth. This transition from an industrial civilization to an ecological civilization contains three dimensions that need to be brought into harmony, according to the Communist Party's constitution: environmental, economic, and social. The elaboration of this vision and policy is a paradigm shift to a new planning approach, a journey of exploration and finding new balances, especially balances between rigid control and flexible adaptation (Xu et al., 2017; Chen and Du, 2018).

Ecological civilization calls for new balances between top-down and bottom-up governance approaches, by exploring public private partnerships and new forms of participation, as mentioned in the final chapter of Shanghai's Master Plan (2017-2035), in short "Shanghai 2035" (SPLRA, 2018a). To supplement this master plan ecological protection (red) lines have been introduced, i.e., zones with building limitations (see **Figure 1A**), to guide and control land use planning (Jin, 2020) and ecological protection around existing and planned "ecological land" (Guo, 2018). This is still in an elementary phase and during the current fourteenth Five-Year Plan (2021-2025) period it will become clear how this will work out in practice. Hopefully these promising expectations can be realized, in stark contrast to a previously proposed green belt in the master plan of 1999 that was completely overrun by urban use over a decade ago (Den Hartog, 2010).

[1]A provincial level municipality under the direct administration of the central government.

[2]"We will resolutely declare war against pollution as we declared war against poverty," said Premier Li Keqiang at the yearly National People's Congress in March 2014. Available online on: https://www.reuters.com/article/us-china-parliament-pollution/china-to-declare-war-on-pollution-premier-says-idUSBREA2405W20140305 (Accessed July 30, 2021).

[3]Available online (Chinese language): http://www.gov.cn/zhengce/content/2016-12/05/content_5143290.htm (Accessed July 30, 2021).

[4]Available online (Chinese language): http://www.gov.cn/xinwen/2021-03/11/content_5592248.htm (Accessed July 30, 2021).

[5]CarbonBrief; 2021. What does China's 14th "five year plan" mean for climate change? Available online: https://www.carbonbrief.org/qa-what-does-chinas-14th-five-year-plan-mean-for-climate-change (Accessed July 30, 2021).

[6]Ecological civilization is a concept proposed by Hu Jintao, general secretary of the Central Committee of the Communist Party of China in 2007. Also see this article in China Daily, available online: http://www.chinadaily.com.cn/opinion/2007-10/24/content_6201964.htm (Accessed July 30, 2021).

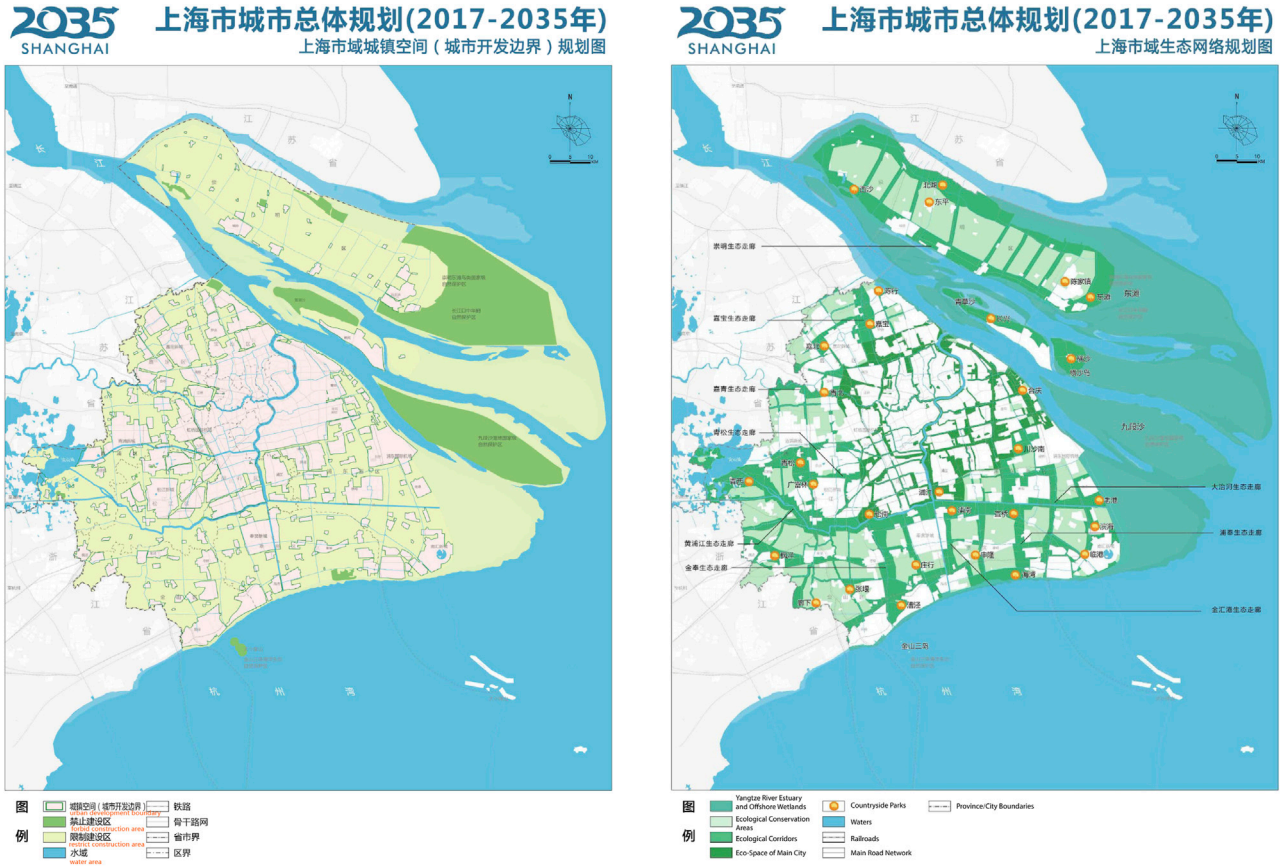

FIGURE 1 | (A) Ecological Protection (Red) Lines with building limitations (Source: SPLRA, 2018a; adjusted by author). **(B)** Eco-network plan of Shanghai (Source: SPLRA, 2018a; adjusted by author).

Ecological Vulnerability in Urbanizing Deltas

Most wetlands are located along rivers or in river deltas. They provide directly or indirectly almost all of the world's supply of freshwater (UN Climate Change News, 2018). Approximately 40% of the world's population lives in deltas. Metropolitan regions, such as the Yangtze River Delta, the Pearl River Delta, the New York metropolitan area, Greater London, the Randstad Holland, Saigon, St. Petersburg and many others, were built on wetlands and swamps. Due to their strategic location, deltas are the location of complex land use conflicts: urbanization, infrastructures, ports, wetlands, and fertile agricultural lands compete for dominance. During last 3 decades the urbanization rate and construction of new urban areas accelerated dramatically, especially in the world's new and rising economies. China is, without doubt, frontrunner in this. As illustrated in the case studies in this paper, in the context of urbanizing deltas, wetlands often loose out. Yet wetlands are crucial ecosystems: about 40% of all plant and animal species live and breed here, and "more than 25% of all wetlands plants and animals are at risk of extinction" (UN Climate Change News, 2018).

Land reclamation, groundwater-level lowering, and other urban influences have diminished wetlands worldwide. The world's wetlands are disappearing three times faster than forests; nearly 35% of all wetlands were lost between 1970 and 2015 (UN Climate Change News, 2018). Since 2000, this process has been accelerating. Worldwide, policy provisions and decision-makers undervalue wetlands according to a report by the global Wetland Convention (UN Climate Change News, 2018); and there is a lack of urban wetland management and policy guidance. Usually there are tensions between conservation and development. However, wetlands have a range of important ecosystem services (Danley and Widmark, 2016), such as rainwater storage or sponge capacities, storm surge protection (Moeller et al., 2014), water purification, carbon sequestration (Sutton-Grier and Howard, 2018), biodiversity conservation, but limited options for urban recreation (limited to protect the wetlands).

Aside from some inland metropolises, such as Chongqing, Chengdu, and Wuhan, most of China's urbanization boomed in a zone of approximately 100 km along its coastline, with extremely high concentrations in the three main delta areas: the Pearl River Delta, the Bohai Rim (Tianjin and Beijing), and the Yangtze River Delta. This rapid growth brought a new urban lifestyle, and improvements in the quality of life for millions. It also brought new problems, such as air pollution, water quality problems, and ecological degradation.

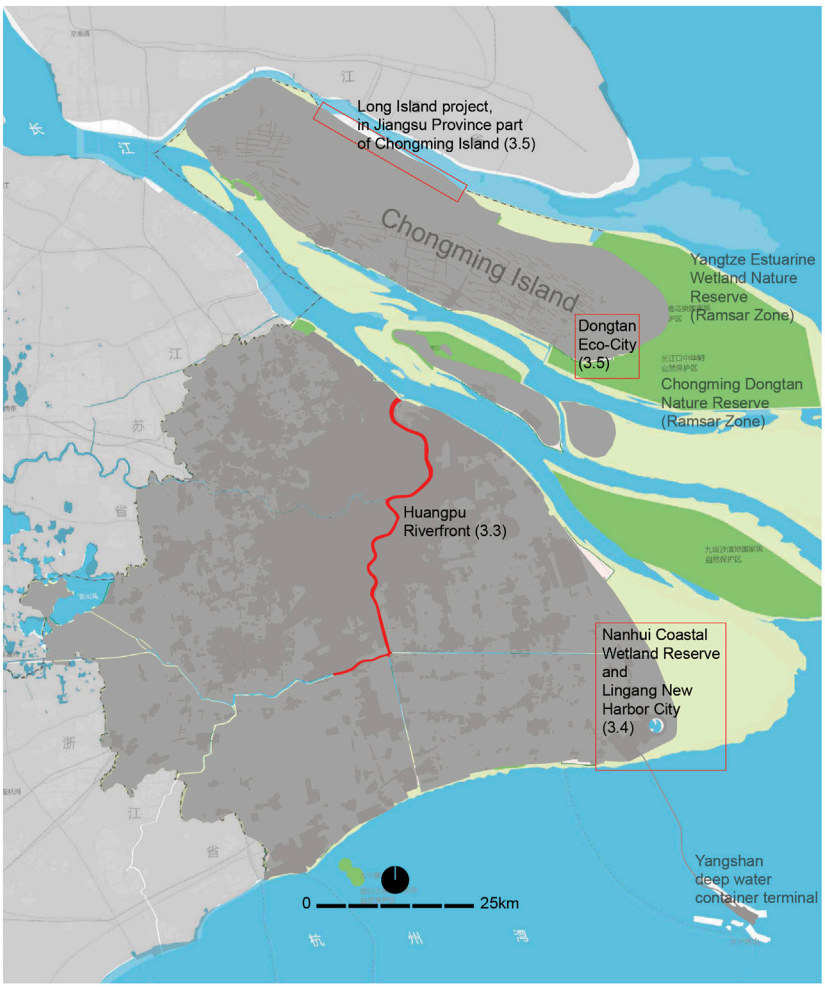

FIGURE 2 | Shanghai Direct Controlled Municipality with the locations mentioned in this article (image by author; green zones as underlay by SPLRA, 2018a).

Since the 1950's more than half of China's coastal wetlands disappeared, 53% of temperate coastal ecosystems, 73% of mangroves and 80% of near-shore coral reefs vanished, according to research by China's State Forestry Administration, Chinese Academy of Science's Institute of Geographic Sciences and Natural Resources Research, and the Paulson Institute,[7] mainly because "huge economic returns from land reclamation have prompted local governments to 'bypass' regulations issued by the central government" (Larson, 2015). Sea reclamation is a relatively quick[8] and cheap way to get more land and profits. Another reason is competing policies, e.g., local authorities are required to safeguard food supply by maintaining a minimum amount of arable land,[9] consequently allowing wetlands—which are often classified as wasteland (Li, 2019)—to be cultivated for farming.

The concept of protecting nature by law is relatively new in China. China's first nature reserve was established in 1990 in Shanghai; consequently in this same city public awareness about environmental issues started to increase gradually (Zhao et al., 2006). This pioneering role of Shanghai will be explored further with help of theoretical framing and case studies in the next sections, to examine the achievements and hurdles in Shanghai's ongoing journey towards an ecological civilization.

[7]A full report can be queried online *via*: https://www.paulsoninstitute.org/conservation/wetlands-conservation/blueprint-of-coastal-wetland-conservation-and-management-in-china (Accessed July 30, 2021).

[8]In many recent Chinese cases the construction of buildings start already within a year, for example in the case of the Long Island project on Chongming (Den Hartog, 2017). However, land needs at least 4 years to get firm and solid, according to Dutch experiences, to prevent damage by subsidence.

[9]Since 2004 the Communist Party has set a red line for China's total arable land, which shall be no less than 1.8 billion mu (120 million ha). See: https://news.cgtn.com/news/3d3d514d316b444f32457a6333566d54/index.html (Accessed July 30, 2021).

CASE INTRODUCTION AND THEORETICAL FRAMING

Aims and Case Selection

This research aims to test how sustainability transitions "thinking" (see *Sustainability Transitions and Experiments*) can be applied in a useful way in the context of Shanghai, with additional insights from ecological civilization "thinking." This paper critically assesses how Shanghai seeks to implement large-scale ecological improvements along its interface between land and water, in former port areas and along the continuously shifting coastline, in the context of extreme urbanization pressure. How is Shanghai dealing with the expectation of a sustainable green transition, and what can we learn from this? How is the city seeking to improve the balance between wetland protection, urban development, and climate change adaptation?

The cases (**Figure 2**) are located along Shanghai's main waterfronts and illustrate conflicts between urban development pressure and ecological values. The first case (*Huangpu River Waterfront as Main Stage for Ecological Civilization*) is the Huangpu River's waterfront transformation in the central city, where former port-related industries make place for a new service-oriented economy (Den Hartog, 2021). The second case (*Nanhui Coastal Wetland Reserve and Lingang New Harbor City*) deals with wetland development that conflicts with Lingang New Harbour City and relocated port areas on large-scale land reclamations along Pudong District's coastline. The third case (*Chongming Eco-Island*) deals with speculative peri-urban new town developments along the edge of Chongming Eco-Island located in the Yangtze River estuary. All three cases form crucial elements in an engineered new eco-network (**Figure 1B**; see *A Green Eco-Network as Socio-Technical Experiment to Support the Transformation of Shanghai into an Ecological Civilization*).

Sustainability Transitions and Experiments

Drawing on insights from scholarship on sustainability transitions and additional insight from ecological civilization (as a National socio-technical experiment), this paper examines how planning ambitions are translated into local realities on the ground, during their planning and implementation process, and afterwards. In the field of sustainability transitions, scholars investigate major shifts toward sustainable socio-technical systems of production and consumption (Markard et al., 2012). Following the main conceptualization of sustainability transitions, which predominantly originate from North- and Western European countries with strong welfare state traditions, some overarching patterns can be identified (Sengers et al., 2016; Kivimaa et al., 2017; Weiland et al., 2017), which are translated into comprehensive lessons on how urbanization processes can be guided towards more sustainable pathways to create attractive and functional new (urban) environments. For this paper, three core concepts from this body of theory are used to frame the empirical analysis and argumentation: 1) expectations, 2) socio-technical experimentation and 3) sustainable innovation journey.

The concept of "*expectations*" is often used in the field of sustainability transitions to explore how actors use appealing visions of a sustainable future in their (urban) development projects. These expectations can be defined as "statements about the future that circulate" (Van Lente, 2012). This idea of circulation is important, because expectations are "performative" by helping to create a new future reality by coordinating roles and activities amongst actors (Konrad, 2006) and by legitimizing certain investments (Borup et al., 2006). Hence expectations should be robust (shared by multiple actors), specific, and of high-quality (Schot and Geels, 2008).

To translate these expectations into realities on the ground, actors need to participate in a process of "*socio-technical experimentation*" (Evans et al., 2016). The expected creative and innovative solutions are tested and developed in real-life settings or urban labs.[10] While testing, a wide variety of societal stakeholders are involved. There are also other external influences that can define the outcome. Unlike experimentation in the natural sciences—that usually takes place under strictly controlled conditions, aimed to find objective certainties—experimentation in the field of sustainability transitions is an open-ended process. Consequently, scholars talk about "socio-technical experiments," which are an: "inclusive, practice-based and challenge-led initiative, designed to promote system innovation through social learning under conditions of uncertainty and ambiguity" (Sengers et al., 2016). Experiments are only meaningful if involved actors are willing to engage and foster social learning, and are open to system innovation when prioritizing their set sustainability goals (Loorbach, 2007).

Socio-technical experimentation in the urban environment is accompanied by an open-ended unfolding innovation journey (Van de Ven et al., 1999), in particular a "*sustainable innovation journey*" (Geels et al., 2008), full of uncertainty (Garud et al., 2014). In the case studies in this paper of this paper a narrative perspective is used to describe these journeys.

In Chinese urban planning and design we can distinguish three types of experiments:

(1) "Pilot-projects" aimed to (re)formulate relevant policies (e.g. a "low-carbon pilot"; Den Hartog et al., 2018);
(2) "Demonstration projects" (or zones) are considered to be successful experiments that can be replicated (e.g., Chongming Island as National Ecological Demonstration Zone; Ma et al., 2017);

[10]For example the "Hunts Point Resiliency" pilot-project in the Bronx, New York City, available online: www.rebuildbydesign.org/our-work/all-proposals/winning-projects/hunts-point-lifelines and https://medium.com/hunts-point-resiliency (Accessed July 30, 2021); or the Living Breakwaters Staten Island, New York City, available online: http://www.rebuildbydesign.org/our-work/all-proposals/winning-projects/ny-living-breakwaters and https://stormrecovery.ny.gov/learn-more-about-living-breakwaters-project (Accessed July 30, 2021); or the multiple samples in Rotterdam, see: https://www.c40.org/case_studies/c40-good-practice-guides-rotterdam-climate-change-adaptation-strategy (Accessed July 30, 2021).

(3) "Civilized projects" are excellent social management models that support political principles (e.g. Wusong Paotaiwan Wetland Forest Park[11]).

The concepts of sustainable development and sustainability follow the definition of The Brundtland Report, which states: "Humanity has the ability to make development sustainable to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs" (United Nations, 1987).

Research Methodology

Empirical evidence for this research is based on site observations, document analyses, and fieldwork by the author. A foundation for data collection was laid during fieldwork with students at the Shanghai University of Finance and Economics as part of the authors' course "city and environment," between 2015 and 2019. During thirty site visits there were short conversations with local people, including farmers, and more in-depth conversations with key-stakeholders, including local officials, entrepreneurs, nature conservation specialists, and urban planners. During fieldwork, design studios and workshops at Tongji University there were more detailed investigations for all three cases (*Huangpu River Waterfront as Main Stage for Ecological Civilization*, *Nanhui Coastal Wetland Reserve and Lingang New Harbor City* and *Chongming Eco-Island*). Desktop research was carried out to review sustainability transitions and ecological civilization literature, and relevant planning documents at the municipal and national level (when needed with translation and interpretation). The author co-organized and participated in knowledge exchange projects in cooperation with various universities in Shanghai and abroad.[12]

The study has some limitations. Although translation was continuously available, the interpretation may be viewed differently in some situations. In the Chinese context, access to reliable numerical data can be difficult. Hence a qualitative research approach has been used in this study.

SHANGHAI'S WATERFRONTS AND COASTLINE AS A LABORATORY FOR ECOLOGICAL CIVILIZATION

Strategic and Exposed Position in the Yangtze River Estuary

The origin of Shanghai is inseparable from its location beside the water.[13] An efficient network of waterways (Ball, 2017; King, 1911) shaped the spatial and economic development of the Yangtze River Delta. Shanghai's waterfronts can be seen as a Frontier where conflicts in land use manifest between land reclamation, urban use, industrial use, agricultural use, and natural conservation. Shanghai's location on the estuary brought prosperity, especially as a result of port activity. It also brought exposure and vulnerabilities: scarcity of fertile lands (Brown, 1995), increasing flood-risk (Balica et al., 2012; Hanson et al., 2011; Ke, 2014; Quan, 2014), and endangered wetlands (Wang, 2012; Li et al., 2020).

Along the coastline there has always been a strip of wetlands that grew by a natural process of sedimentation. This process of an eastward shifting coastline largely created the territory of Shanghai. Especially since the 1950s, this process has been accelerated by means of breakwaters and land reclamation. Under Mao's leadership, there was a shift toward technocratic engineering: "Man must conquer nature" (Shapiro, 2001). Natural capital and landscape values were neglected. Moreover, urban planning practices were principally based on a tabula rasa approach, which largely ignores existing natural and cultural-historical values. Many natural waterways in this region were transformed into canals, while others were dammed or filled in completely. Supported by the new principles of the socialist market economy, financial motivations (Harvey, 2005) began to dominate planning and land-use practice, often with additional collateral damage for ecosystems and quality of life for residents (e.g. various forms of pollution, resettlement). Increasing land scarcity forced Shanghai to create new land through land reclamation.

Besides changes in sedimentation due to a decrease in discharge after construction of the Three Gorges Dam in 2003 (Yang et al., 2005), the wetlands along Shanghai's coastline became increasingly under threat by land reclamation. Approximately 40% of Shanghai's estuarine wetlands have been lost since 1980 due to land reclamation, totaling 816.6 km^2 between 1974 and 2018 (Li et al., 2020). The main uses of the reclaimed lands have been agriculture and urban expansion—planned new town construction on Chongming Island (see *Chongming Eco-Island*), and Lingang New Harbor City (see *Nanhui Coastal Wetland Reserve and Lingang New Harbor City*), Pudong International Airport, tap water storage areas, recreation (golf), and port relocation (from the Huangpu River to along the coastline).

A decade ago scientists warned that Shanghai faced a serious risk for a "once in a 100 years flood," with serious consequences,[14] and possible economic impacts far beyond the city (Balica et al., 2012; Hanson et al., 2011; Ke, 2014; Quan, 2014). Since then substantial flood protection measures have been implemented along the Huangpu River, in the form of 7-m high retaining walls. Also, in the Pudong District, coastal dikes have been reinforced, and make Shanghai—except Chongming Island—better prepared for flood risk compared to some other financial centers (Xian et al., 2018; IPCC, 2019).

These efforts have been convincingly combined with the regeneration of polluted industrial waterfronts and

[11]CGTN (2018). Shanghai turns a steel slag field into a wetland forest park. Available online: https://news.cgtn.com/news/3d3d674d3351444e79457a6333566d54/index.html (Accessed July 30, 2021).

[12]The cases in this paper were the subject of previous studies by author: Chongming Island (Den Hartog, 2017; Ma et al., 2017; Den Hartog et al., 2018; Den Hartog, 2019), Nanhui (Den Hartog, 2010), and the Huangpu River's waterfront (Den Hartog, 2019; Den Hartog, 2021).

[13]The city's name literally translates as "upon the sea."

[14]Also see this animation by Climate Central's Program on Sea Level Rise, available online: https://choices.climatecentral.org/#11/31.2307/121.4738?compare=temperatures&carbon-end-yr=2100&scenario-a=warming-4&scenario-b=warming-2 (Accessed July 30, 2021).

FIGURE 3 | Hard embankments in new ecological park along the Huangpu River (Photo by author, September 2020).

construction of beautiful manicured public spaces (Den Hartog, 2019). However, the 'hard' technocratic solutions with flood prevention infrastructure (**Figure 3**) constitute barriers for ecological development, e.g., concrete embankments do not provide nesting opportunities for fish, birds, and other species and will need to be addressed (Gan et al., 2018).

Along the coastline of Nanhui (see *Nanhui Coastal Wetland Reserve and Lingang New Harbor City*), many wetlands (including salt marshes, mud flats and portions of the estuary water body) have been diked—constructed at 2 m depth below the minimum low-tide level—to speed up siltation reclamation for urban purposes (Tian et al., 2015) instead of benefitting from the storm surge protection capacities of wetlands (Moeller et al., 2014)—and converted into aquaculture farming or agriculture, which adds to flood risk (Cui et al., 2015). To compensate for the collateral damage of extreme rapid urbanization, Shanghai has been searching for ways to protect existing wetlands and stimulate the development of new wetlands, which currently looks like more of an ecological engineering effort than ecological restoration, as will be described in the next sections.

A Green Eco-Network as Socio-Technical Experiment to Support the Transformation of Shanghai into an Ecological Civilization

Promising Expectations in "Shanghai 2035"

Following the master plan's promising subtitle "Striving for an Excellent Global City" Shanghai wants to compete with, and possibly surpass, other global cities such as New York, London, Paris, Singapore, and Tokyo in terms of economy, image, and quality of life. Shanghai commits itself to become a benchmark for international megacities in terms of green, low-carbon and sustainability" (SPLRA, 2018a). Shanghai 2035 further states: "the world has stepped into an era of ecological civilization that puts environmental friendliness and a humanistic approach first." By developing multiple pilot-projects Shanghai wants "to play a pioneering role" and "take the lead" by becoming an "environment-friendly, economically-developed, culturally-diversified, safe and livable city" (SPLRA, 2018a). In poetic words, the master plan further states that "citizen happiness" is fundamental to development, and because of this, "Shanghai strives to build a prosperous and innovative city." According to the master plan Shanghai also wants to become more adaptable to climate change and resilient. All of this should be realized by engineering "a desirable ecological city," which is explained as "a beautiful space that meets the demands of the increasing number of citizens, where the water is more blue and the land is more green, and one lives in harmony with nature [. . .] to satisfy the citizens yearning for a better life" (SPLRA, 2018a). The two terms "beautification" and "harmonization" have been increasingly used in ecological civilization campaigns since 2007 (Hansen et al., 2018). The realization of an ecological civilization is a nationwide socio-technical experiment, for which Shanghai will play a guiding and pioneering role. In 2015, local authorities started constructing an Overall Plan for Ecological Civilization System Reform, which has been integrated in the master plan Shanghai 2035.

Socio-Technical Experimentation With Green Infrastructure

A key project in this sustainable innovation journey toward an ecological civilization is the construction of a blue and green interconnected eco-network with at least 60% of the municipal territory restored or conserved for ecologic functions (**Figure 1B**), which is an increase of ten percent. Extensive new wetlands and a variety of ecological restoration and engineering projects are planned,

ranging from national parks (two on Chongming), city parks, and +1,000-m wide green corridors to community-based pocket parks and vertical greenery on buildings. Many of these green spaces have already been implemented since 2017, partly accelerated and prioritized due to the Covid-19 crisis. Similar to the Green Belt around London and other green buffers, such as the Green Heart of the Randstad metropolis in the Netherlands, a main function of Shanghai's new eco-network is to "satisfy citizens' diversified leisure demands," but also to enhance ecological diversity (SPLRA, 2018a). The eco-network aims to get citizens closer to nature and reconnect the city with the countryside, explained as the so-called "introducing the forest to the city"-policy (SPLRA, 2018a). Moreover, this green infrastructure is mentioned as a new backbone for urban development (instead of rails or asphalt).

Sustainable Innovation Journey Toward an Ecological Civilization

In the early phase of implementing this eco-network, many local hurdles became apparent and limited anticipated ecological connectivity (Liu et al., 2019). The experimental projects, as described in the next three sections, are important components in this eco-network. Each started early this century, and important lessons can be distilled from their sustainable innovation journeys. A main problem is a lack of clarity about the definition of "ecological land" (as explained in Sections *Nanhui Coastal Wetland Reserve and Lingang New Harbor City* and *Chongming Eco-Island*), resulting in a mismatch between outcomes and expectations. Ecological land is defined in Shanghai 2035 as "land that is used to provide ecosystem services in the city, including green land, forest land, garden land, cultivated land, tidal flat reed land, pond aquaculture water surface, unused lands, etc." (SPLRA, 2018a). In fact this appears to be all the land that is not build upon or paved, and it even includes large water surfaces (compare **Figures 1A,B** with **Figure 2**: grey color on **Figure 2** is current land surface). Hence, the ecological value of these spaces obviously varies. Shanghai's rapidly increasing number of roof gardens and green facades can have ecological value, and at the same time, there are un-built and unpaved lands that have less ecologic value such as golf courses.

Huangpu River Waterfront as Main Stage for Ecological Civilization

Expectations and Socio-Technical Experimentation

Shanghai's most spectacular project is the urban regeneration of the Huangpu River's waterfront that used to be dominated by port-related industries. The river is intended to become a key component of the envisaged eco-network,[15] a "green and low-carbon demonstration zone" (SPLRA, 2018a), and crucial contributor to realize the aspiration of an ecological civilization. In the context of extreme urban density, the riverfront is expected to form a continuous open public space as "urban living room", to emphasize Shanghai's identity as a port city, and to create new ecological connections (**Figure 1B**). It is simultaneously the main contributor to becoming an "Excellent Global City." In 2018, the Huangpu Waterfront became officially a "demonstration zone for the development capability of the global city of Shanghai" (SPLRA, 2018b). The importance of this project is underlined by an inspection visit of a section of the waterfront in Yangpu District—within the overall demonstration zone this relative short section is earmarked as demonstration zone for the construction of a people-oriented city (**Figure 4**)—by General Secretary Xi November 2019,[16] and a possible revisit during Summer 2021, most likely followed by a visit of Chongming Island.

Sustainable Innovation Journey

Combining urban regeneration of former industrial waterfronts with ecological development is an immense challenge, especially due to increasing land scarcity, towering real estate prices, and the necessary integration of a flood defense system. Most polluting industries have already been relocated to beyond the edge of the city (e.g. along the coast of the Pudong district and on Chongming Island) with more space to grow, and even to other provinces. Plans are underway to relocate the last remaining industries, such as the government-owned Baosteel (see *Expectations and Socio-Technical Experimentation*), the second largest steel producer in the world. This measure adds to the reduction of carbon emissions within the city limits and improves the general image and quality of life—to make place for a scenic recreational landscape. In less than 5 years, a very attractive more than 50 km of public waterfront with greenery, and biking and walking trails emerged along the Huangpu, offering a welcome and pleasant relief of the urban congestion.

Yet the new greenery along the Huangpu River is maintained with a people-oriented approach. As observed during field research, pesticides are frequently used to control the manicured newly green landscape. Decorative flowers (good for taking selfies) are preferred instead of the spontaneous growth of species. To accommodate urban use and set priorities for certain areas within the limited available space, zoning has been proposed by experts from Tongji University (**Figure 5A**) with four different categories: 1) "Eco for charming," which means decorative green in a high-density urban context (**Figure 4**); 2) "Eco for sharing," in a context with more space for green that can be used for recreational purposes; 3) "Eco for symbiosis," in a residential context; 4) "Eco for wilderness," which is not accessible to people. In the first three categories, the principle of so-called stepping-stones has been introduced, which means the creation of micro-greens for birds and other species that can hop from one stepping-stone to another one, adding to ecological corridors (Gan et al., 2018). A stepping-stone could be an eco-friendly architectural feature for breeding and shelter (e.g. green walls and roofs), a small (floating) island, or ecological hanging bags along embankments, or ecological slopes. After the urban planning bureau of Shanghai adjusted the proposal (**Figure 5B**), dozens of stepping-stones were introduced (**Figures 4**, **6**, **7**). "Eco for wilderness" is yet to be found along the Huangpu River, but hopefully this will be realized by 2035, at

[15]According to the Shanghai Huangpu River and Suzhou River planning (SPLRA, 2018b) the ecological space along the Huangpu River will increase with 1,000 ha "to improve the ecosystem, improve the quality of space, and build an excellent global city."

[16]Impressions available online on: http://www.xinhuanet.com/english/2019-11/02/c_138523489_2.htm (Accessed July 30, 2021).

FIGURE 4 | People oriented "Eco for charming" along the Huangpu River in Yangpu District (Photo by author, May 2021.

the end of the journey, as set in Shanghai's master plan. Priority has been given to removing polluting industries and improvement of the area's public image with manicured greenery. A next step in the ongoing sustainable innovation journey is expected to add more ecological values.

The greening projects so far formed the setting for massive real estate projects that were constructed here from 2012 (Den Hartog, 2021). All these new buildings received green labels to match the National Green Building standard, especially regarding low-carbon emissions. Although in practice the application of these standard is still questionable (Den Hartog et al., 2018), and a very large share of the newly built buildings is used for speculation purposes and remain mainly empty even several years after completion and before the COVID-19 crisis started (Den Hartog, 2021).

Nanhui Coastal Wetland Reserve and Lingang New Harbor City

Expectations and experimentation to create a "future coastal city"

Another locality that embodies the clash between urbanization pressures and ecological protection or restoration is the Nanhui Coastal Wetland Reserve (**Figures 2**, **8**, **9**) at the edge of Shanghai's Pudong District, under the flight path to Pudong International Airport. A significant portion of this 122.5 km^2 land reclamation project is earmarked for urbanization. In 2002, when the area was a tidal flat, it was expected that the pilot project Lingang New Harbor City would grow here into a city with 800,000 inhabitants by 2020 (Den Hartog, 2010). This new city accompanies the Yangshan Deep-water Port complex, which opened in 2010, today the largest container terminal in the world in terms of capacity. Nearby new (heavy) industry complexes have been erected, partly as a relocation area for the regenerated waterfronts along the Huangpu River downtown. The promising expectation was to create a "future coastal city" with advanced manufacturing, shipping trade, and marine industry. Lingang New Harbor City was expected to function as "demonstration zone of reform and opening-up, driven by system innovation" and "intellectual and cultural innovation."

Sustainable Innovation Journey and Conflicts With Wetland Restoration Efforts

But, due to the remote location, lack of facilities, and poor building conditions (many buildings suffer serious moisture problems), as well as fluctuations in the expected port development and international container transport, the sustainable innovation journey of this new city stalled. More than half of the realized buildings were still empty in 2021. About three quarters of the planned city actually has yet to be built. Under influence of the nearby Ramsar zones[17] on Chongming Island, the coast of Nanhui became an important transit area for migratory birds, with rich biodiversity. According the original

[17]Chongming Dongtan Nature Reserve, Shanghai, https://rsis.ramsar.org/ris/1144; Shanghai Yangtze Estuarine Wetland Nature Reserve for Chinese Sturgeon, https://rsis.ramsar.org/ris/1730 (Accessed July 30, 2021).

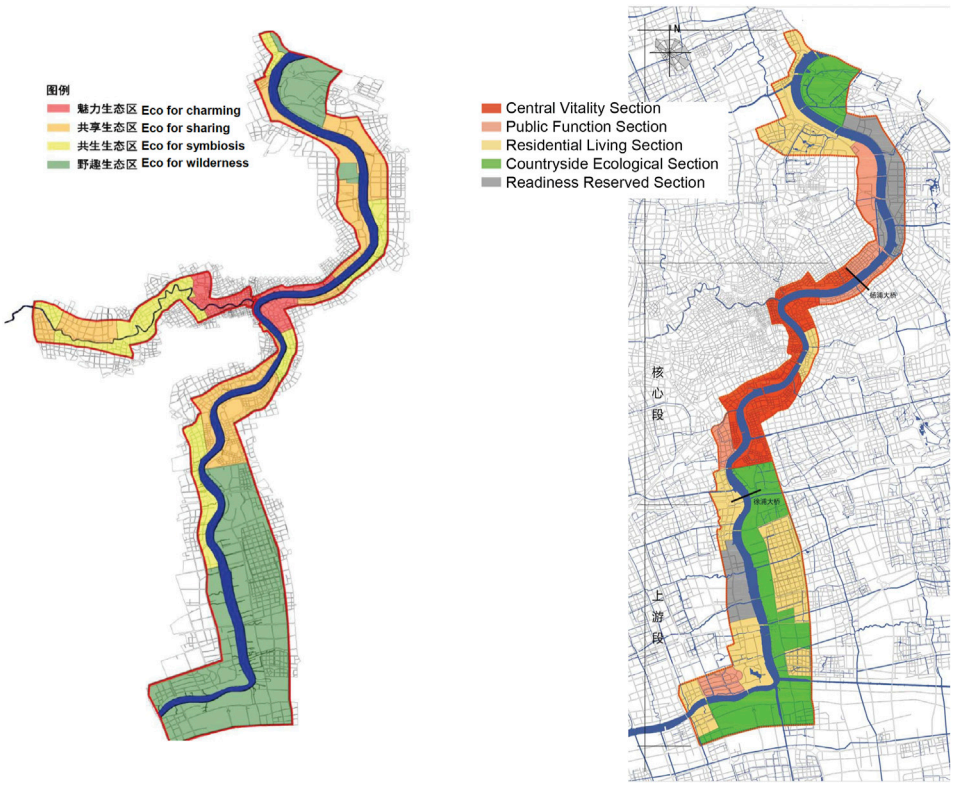

FIGURE 5 | (A) Proposal for ecological dimensions along the Huangpu River (Source: Gan et al., 2018). **(B)** Functional zones along the Huangpu River according to municipal planning bureau (Source: SPLRA, 2018a).

FIGURE 6 | Ecological 'stepping-stone along the Huangpu River at Lujiazui, the city center (Photo by author, March 2020.

FIGURE 7 | Ecological 'stepping-stone along the Huangpu River at the former World Expo 2010 site (Photo by author, March 2020.

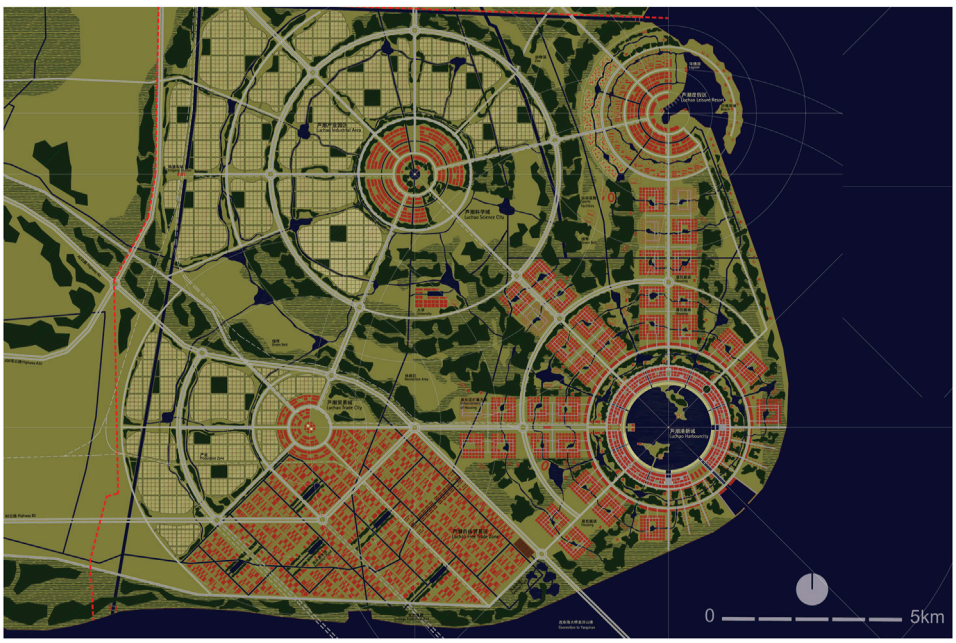

FIGURE 8 | Master plan Lingang New Harbor City with 800,000 inhabitants on top of 122.5 square kilometers reclaimed wetland. Only a quarter of this city and its green buffers has been realized, a large share of the buildings is empty and remaining lands have various usages, mainly farming or recreation (Source: GMP 2001; adjusted by author).

plan, the new city was to be surrounded by lush nature and wetlands. However, a large part of the lands reserved for nature development currently has other land-uses, such as aqua farming and plantations. From an agricultural point of view, wetlands are often seen as wastelands (Li, 2019) and farming, including aquaculture is prioritized above nature conservation, especially in times of increasingly scarce agricultural resources (Brown, 1995). Wetlands are even defined as unused land in China's land

FIGURE 9 | Wetlands partly used for farming at Nanhui in the Pudong District. Lingang New Harbor City was planned here (Photo by author, December 2018).

classification system (Lin, 2009) and consequently are often converted to agriculture.[18] Many stakeholders underestimate the value of ecosystem services (Wang et al., 2019). Ecological restoration needs understanding and systematic research, since ecosystems are sensitive and complex systems. For example, the soil structure and silt on coastal marshes make it inhospitable for most trees, and especially unsuitable for a cypress plantation, which is the case now (Li, 2020). A group of environmentalists, scientists, and nature enthusiasts launched a protest to raise international awareness to counter this threat, especially since Tesla's new Gigafactory started construction near here (Brelsford, 2019).

Chongming Eco-Island

Expectations and Socio-Technical Experimentation

Chongming Island, located in the estuary of the Yangtze River lies within the municipal border of Shanghai. The 80 km^2 large Dongtan area is a former state farm, located in Chenjia Town one of the 18 administrative subdivisions of Chongming Island. At Dongtan, on the east end of the island, there are two zones appointed as "wetlands of extreme international importance" by the Ramsar Convention, 2018.[19] Already in 1996 the National Government nominated Chongming as an eco-island, and in 2001 the expectation for this eco-island was "to explore experiences of sustainable development for China's cities and towns and provide excellent model exemplars" (MOST, 2001). It became the site for several experimental projects, including the promising pilot project for Dongtan Eco-city (Den Hartog, 2010). As recently as 2009, the whole island was designated officially as National Experimental Zones for Sustainable Development, and in 2017 this status was upgraded to National Ecological Demonstration Zone (Ma et al., 2017).

Sustainable Innovation Journey and Conflicts With Wetland Restoration Efforts

The effectiveness of this eco-island-policy becomes clear when studying the northwestern edge of Chongming, which falls under jurisdiction of Jiangsu Province, and is consequently excluded from the National Ecological Demonstration Zone. Serious conflicts in land use arose there when under the guise of protecting land through conservation development (Milder, 2007), natural wetlands were reclaimed and opened up opportunity for massive speculative real estate. This deviation from the intended sustainable innovation journey toward an ecological demonstration zone on the part of the island that isn't administered by Shanghai occurred due to inadequate supervision, and especially poor communication between various responsible authorities at municipal and provincial levels. A profit-seeking developer (Greenland, which is state-owned and Shanghai based) and local governments in Jiangsu Province started a joint project here named "Long Island," which envisaged a new town for 100,000 inhabitants, but it was not inhabited because of its remote location and it has been used for speculative investment (**Figures 2**, **10**, **11**; Den Hartog, 2017). This has added to the already severely disturbed ecosystem along the north-branch of the estuary, subject to ongoing degradation since the 1950's (Guo et al., 2021), and prone to flood risk (see *Strategic and Exposed Position in the Yangtze River Estuary*). Two similar projects were built there as well. After negative media attention, the central government took over control of the project and started to intervene; halting construction and threatening to demolish all newly constructed high-rise buildings, although the buildings remain (Den Hartog 2019).

This experience illustrates that experimental demonstration zones and pilot-projects need thorough preparation and

[18]See this article available online at: http://www.ecns.cn/2015/10-30/186433.shtml (Accessed July 30, 2021).

[19]Chongming Dongtan Nature Reserve, Shanghai, https://rsis.ramsar.org/ris/1144; Shanghai Yangtze Estuarine Wetland Nature Reserve for Chinese Sturgeon, https://rsis.ramsar.org/ris/1730 (Accessed July 30, 2021).

FIGURE 10 | Long Island real estate project and related projects, located in the Jiangsu Province part of Chongming Island, constructed since 2014 on top of more than 12 square kilometers reclaimed wetlands; most buildings are empty (Map by author and Jiawei Hu).

FIGURE 11 | Fragment of the speculative Long Island real estate project in the Jiangsu Province part of Chongming Island (Photo by author, July 2019).

supervision beyond municipal boundaries, and clear communication with all stakeholders. Another example of problems with implementation of this National Ecological Demonstration Zone occurred near the Ramsar zones at the eastern edge of the island. From the early 1990's *Spartina alterniflora*, an invasive species used to stabilize shoals to make them ready for reclamation, appeared on Chongming Island. As a consequence of its rapid spreading, wetland biodiversity declined (Zou et al., 2014). In parallel, even with the introduction of the National Ecological Demonstration Zone, land reclamation continued, even within natural reserve areas. This

FIGURE 12 | Master plan for Dongtan Eco-city, good for 500,000 inhabitants. The plan has never been realized; resorts with in total more than a thousand speculative (seldom used) luxurious villas and a golf course have been built here instead (Source: Arup, 2005).

happened under the guise of removing invasive plants (Xie et al., 2020).

One of the first actions to counter these practices was the WWF-China Flyways program, which was financially supported by multiple companies including Coca-Cola, and the Kingdom of Netherlands.[20] This pilot-project started in 2014 and aimed to reduce and control the *Spartina alterniflora*. The program involved environmental stewardship on Dongtan wetland by involving local communities and farmers, and by introducing principles and practices of waterbird-friendly aquaculture. As a result, the number of waterfowl species has increased significantly (Shanghai Daily, 2017). The innovation journey of Chongming Eco-Island shows that a sustainability transition can't be a readily achievable instant solution. Even in a central controlled State, it is a long-winded process of adjusting and adapting, especially due to its many dimensions and large scale. It includes both successes (e.g. the before-mentioned WWF-China Flyways program) as well as failures, such as the demise of Dongtan Eco-city located besides the Ramsar zones (**Figures 2**, **12**), where luxurious apartments have been built along a golf course, mostly empty, that are used for speculative investment instead of the promised ecological dream city (Den Hartog et al., 2018).

DISCUSSION

What can we learn from Shanghai's sustainable innovation journey? How might the city improve the balance between wetland protection, urban development, and climate change adaptation? The above-examined cases show that despite good intentions and central control, expectations can still differ from end results. Apart from advantages in terms of speed, scale and Chinese decisiveness, we can learn that (severe) collateral damage to the environment can still occur, e.g. because of inconsistent definitions of wetlands (see Section *Nanhui Coastal Wetland Reserve and Lingang New Harbor City*), or because of greed and inadequate communication between different authorities (see Long Island in Section *Chongming Eco-Island*).

Expectations and Conflicts

The "statements about the future" (Van Lente, 2012) regarding the eco-network in Shanghai's current master plan are practice-based and challenge-led, and steered by ecological civilization in an attempt to balance environmental, economic, and social aspects. These statements are certainly robust–because state-led, specific, and of high quality (Schot and Geels, 2008). The promises and content of Shanghai 2035 showcases the absorption of international knowledge and practices, and even has the ambition to surpass other global cities in terms of speed, and scale, and quality. The new Huangpu waterfronts are breathtaking. It is remarkable that they were realized in such a short timespan. In addition, the amount of urban greening in the city as a whole, with green buffers and new coastal wetland, all integrated into a new eco-network, largely already under construction, is unprecedented.

This is impressive but distracts from substantive necessary quality and long-term goals. The cases on Chongming (Section *Chongming Eco-Island*), and along the Huangpu River in downtown Shanghai (Section *Huangpu River Waterfront as Main Stage for Ecological Civilization*), are primarily aimed at improving the (public) image and status, to attracting (foreign) investment, and to accommodate a selective upper middle class with a comfortable living environment

[20]See also: https://www.eaaflyway.net/signing-of-the-mou-between-the-chinese-state-forestry-administration-and-wwf-china (Accessed July 30, 2021).

(Den Hartog, 2019). This is also a form of environmental injustice and contradicts the principles of an ecological civilization (Pan, 2006). For example, relocation of polluting industries might be good for downtown citizens, but causes conflicts on the new locations of these still polluting industries.

Socio-Technical Experimentation and Learning Factors

In the Global North, the key role in sustainability transitions shifts from the national governments toward local governments, especially cities (Sengers et al., 2016). Even in a strongly centrally controlled country as China local governments play a decisive role—in the case of Shanghai even on district level as we found in the case studies—and in particular the translation and communication into everyday practice and usages by local people is decisive.

According to Evans et al. (2016) "urban experimentation" could become a new mode of governance that turns cities into laboratories for the future, especially in the context of welfare states that are increasingly under pressure, and "decreasing possibilities of national state actors to shape sustainability transitions" (Sengers et al., 2016). In the European centered discourse Karvonen (2016) claims that this type of experimentation could supplement or even replace traditional urban planning approaches. Karvonen (2016)explains that in the Global North local authorities frequently use it to mask a lack of funding, or to suggest public-private partnerships. In short, it often represents the erosion of the role and responsibilities of the state, by increasingly outsourcing expertise to citizens and non-Government stakeholders.

Yet in the case of Shanghai this is absolutely the opposite due to a very different socio-political setting. In the People's Republic of China the state uses experimental pilot projects and demonstration zones to set standards and guidelines. The pilot-projects and demonstration zones as described in this paper are socio-technical experiments, but differ from urban labs and experiments, in scale, timeframe, and because far fewer stakeholders participate directly in these state-led processes. This makes their innovation journeys less inclusive. The terms "pilot-project" and "demonstration zone" suggest a certain degree of control of the experiment aimed to prevent failure, opposed to the term "urban lab." This makes pilot-projects and demonstration zones different from the definition in Section *Sustainability Transitions and Experiments*, because experiments do not guarantee success; they can fail (Garud et al., 2014; Sengers et al., 2016). Failure includes a learning factor.

Sustainable Innovation Journey and Civic Engagement

Limiting participation to a select group of stakeholders also excludes feedback as a possible enabler for learning, e.g., as we saw in Section Chongming Eco-Island (Xie et al., 2020). Yet this means that the implementation speed of pilot-projects and demonstration zones can be accelerated, also because of state ownership and mandate over land and resources. Consequently the state-led approach in Shanghai (China) can be more radical and large-scale. This makes the design and implementation of pilot-projects and demonstration zones less uncertain (Garud et al., 2014) and less open-ended as an unfolding sustainable innovation journey (Van de Ven et al., 1999). Denying learning potential is opposed to an adaptive management approach and a hurdle for system innovation.

In the sustainability transitions discourse, experimental approaches and urban labs are expected to lead to innovative, integrated, and inclusive policies and solutions. This can be more easily achieved if sustainability learning is co-created and shared. Coercive environmentalism is certainly no guarantee for successful sustainable solutions (Li and Shapiro, 2020). Actually public participation and consultation were included in China's constitution during Mao's reign, but neglected afterwards. Participation needs to be reprioritized again, including in China's environmental policymaking, according to Li and Shapiro (2020). As indicated in Section *Toward an Ecological Civilization*, ecological civilization calls for new balances between top-down and bottom-up governance approaches and new forms of participation, which is underlined in Shanghai 2035, but is still in an elementary phase in practice. Consultation and transparency are essential to realize a true ecological civilization. Feedback from civil society will improve the outcomes from pilot-projects and demonstration projects, and will likely make policies more effective and sustainable. Yet, this is less likely under the current prevailing Chinese system of governance, as can be seen in the urban regeneration processes along the Huangpu River that lack an inclusive approach (Li and Zhong, 2020; Den Hartog, 2021).

This complexity underscores that a true ecological civilization involves an innovation journey of gradual adjustment and understanding, which cannot be implemented top-down at once, but needs to be more inclusive with a wide variety of societal stakeholders, e.g., such as happened at the initiative of the WWF on Chongming Eco-Island (see *Chongming Eco-Island*) and the use of incentives to stimulate grassroots experiments with eco-farmers (Den Hartog et al., 2018).

CONCLUSION AND RECOMMENDATIONS

It is encouraging that China, with Shanghai as a frontrunner, is attempting to restore[21] the damage done by radical urbanization to the natural environment. Based on the findings in the case studies and the discussion in the discussion some concluding recommendations can be made, aimed to reduce discrepancies between expectations and the reality of daily life. Despite Shanghai's intentions to raise awareness about environmental challenges and its ambition to play a leading role in enabling a green transition, there are still hurdles to be faced.

Expectations Need to be Co-Created and Shared

To translate expectations into realities on the ground these expectations need shared understanding, including agreed

[21]In 2018 China's State Council launched a new regulation on land reclamation to further protect coastal wetlands (State Council, 2018), hopefully more adequate than previous rules. Also see this criticism online: https://chinadialogue.net/en/nature/9814-will-china-s-new-wetlands-protection-rules-be-adequate (Accessed July 30, 2021).

definitions of key concepts, to prevent problems as occurred in Nanhui (*Nanhui Coastal Wetland Reserve and Lingang New Harbor City*) and Long Island (*Chongming Eco-Island*) where the appreciation and evaluation of ecological assets such as wetlands differed amongst various stakeholders. During fieldwork it became clear that terms like "green" and "ecology" are primarily used for making a place visually attractive instead of to increase biodiversity. Policy terms as "beautification" and "harmonization" create high expectations, but may not be realized in daily-life if their intended meaning is not robust (shared by all actors) and not specific (Schot and Geels, 2008). There is a worrying discrepancy in the evaluation of ecosystem services and the daily-life use and protection of wetlands. Therefore a main concern is to acknowledge these ecosystem services. To build shared expectation, the first recommendation is to use widely understood definitions, supported by local leaders and well informed by scientists (e.g. universities and nature conservation organizations) and to communicate this understanding clearly with all stakeholders to guide the innovation journey toward urban sustainability and ecological civilization (recommendation 1).

A co-created shared vision is essential to realize a sustainable innovation journey (Geels et al., 2008) in the long run. Also in line with the ecological civilization philosophy and participation traditions (Li and Shapiro, 2020), new ways of involving citizens in State-led processes need to be explored, to co-create a shared vision for the future, and by working with communities to better understand their needs and aspirations (recommendation 2).

Socio-Technical Experimentation Requires Research About Needs and Consequences

The experimental new cities Lingang (*Nanhui Coastal Wetland Reserve and Lingang New Harbor City*) and Dongtan (*Chongming Eco-Island*), as well as the commercial development on Long Island (*Chongming Eco-Island*), are all constructed on exposed and vulnerable locations, in conflict with existing ecological values (Cui et al., 2015), and subject to flood risk (Wang et al., 2015). Additionally all three mentioned locations have problems with attracting inhabitants because of their remote locations and disturbing speculative ownership—most building are used as investment objects, especially as second houses by new middle-class families in Shanghai–, resulting in desolate communities and a waste of resources.[22] This conflicts sharply with the international accepted definition of sustainability (United Nations, 1987) and also with the idea of harmonious interaction with nature as in ecological civilization. It is recommended that clear policy guidelines are developed to guide property development to ensure public safety and sustainability including wetland protection (recommendation 3).

A Sustainable Innovation Journey Should be a Social Learning Journey and This can Benefit From Citizen Engagement

A sustainable innovation journey needs to be developed through a joint experimental learning approach—e.g., by approaching wetlands as valuable asset with ecosystem services—to be able to effectively protect the remaining wetlands. If an experiment is co-defined as being inclusive and "designed to promote system innovation through social learning" (Sengers et al., 2016) it is essential to involve more actors who are willing to engage and to foster social learning (Loorbach, 2007), including farmers, fishermen, and users in daily life (recommendation 4).

In China, local governments generally have a decisive executive role, while the higher levels of government (provincial and national) have more of a policy-prescribing and supervisory role. Due to various reasons (e.g., lack of experience, time pressure, mismanagement) sometimes things go wrong at local executive level. To prevent this supervision is essential during all stages, and beyond (municipal) planning boundaries (recommendation 5)—e.g., in the case of Long Island (*Chongming Eco-Island*) a supervising team was formed after the damage was done, because the responsible officials could not and did not want to exert influence on the other sides of the municipal and provincial border line.

China, with Shanghai ahead, is shifting from a production economy towards an urban consumption society. During the innovation journey of trial and error, there is a search for a harmonious balance between wetland protection, urban development (including economic aspects, social aspects, etcetera), and climate change adaptation. At the moment it is too early to draw conclusions on the functioning of the new ecological corridors, since only some of them have been implemented so far. Ecological civilization has an anthropocentric emphasis, which is understandable in the context of extreme high population density and the desire for economic catch-up. But to be fully sustainable, eco-friendly and effective in reducing risks (Greenpeace East Asia, 2021) caused by climate change and to restore ecosystems (UN Environment, 2019), there is an urgent need to step beyond this anthropocentric approach (recommendation 6).

Another recommendation is to recognize the reality of uncertainty and ambiguity during the innovation journey of experimentation, to create conditions and opportunities for deliberate social learning and policy adjustments, and correct and steer the project at an earlier stage with creative planning and decision-making processes that are more experimental in nature (recommendation 7).

More thoughtful and better-prepared experiments are urgently needed to further establish Shanghai as a world-leading lab for sustainable urban planning and design, and to fulfill the sustainability transition journey toward achieving the Sustainable Development Goals (UN Habitat, 2015) and also the goals of an ecological civilization. Shanghai's journey differs from established cities in the Global North,[23] and needs to deal with a different audience, with a different background, experience and life-style. Consequently there are other priorities and expectations. The innovation journey towards an ecological civilization will have significant impact on daily life in

[22]Well-known designers and engineers from the Global North designed the master plans for these three new cities.

[23]Environmental pressure in China rose quickly last few decades due to extreme urbanization. Additionally we need to realize that a large share of the polluting industries that contributed to the environmental pressure are relocated (to Shanghai) from countries in the Global North, partly as result of carbon trading policies (Pan, 2006). Meanwhile China is currently outsourcing a lot of its environmental degradation to other countries, for example timber trafficking, see: https://newsroom.ucla.edu/releases/furniture-from-china-contributes-to-deforestation-in-central-africa (Accessed July 30, 2021).

China, and far beyond. The expectations as described in the current master plan span till 2035, thus many unforeseen changes will occur. Hence it remains a journey full of uncertainty.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants, in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

The author confirms being the sole contributor of this work and has approved it for publication.

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Path Dependency and Future Adaptation of Coastal Cities: Examples From the Asia-Pacific

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The need for Asia-Pacific coastal cities to adapt effectively and sustainably to accelerating (relative) sea-level rise is growing. If such adaptation does not occur in a timely manner, then it could result in socio-economic problems that will reverberate throughout the region. Using examples of coastal Asia-Pacific cities that are characterised by contrasting geographical settings and cultural contexts, this study argues that the main barrier to such adaptation is path dependency. In this sense, path dependency is a legacy of past decisions that have been influenced by topography, economic goals, and the cultural-political characteristics of key decision-making groups. These path dependencies manifest as various adaptation preferences, which to date have been dominated by hard engineering solutions. In an era of accelerating climate change there is now a need to seek alternatives to *in-situ* urban growth. This paper argues that an understanding of a city's path dependency is key to optimizing the effectiveness of future adaptation.

Keywords: coastal management, climate change adaptation, path dependency, urban futures, sea-level rise, urbanization, sustainable futures

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INTRODUCTION

All the world's large cities face challenges of sustainability in the future, many arising from rapid rates of recent growth in which economic development has been preferenced over issues affecting quality of life such as water management and pollution, amenity provision and overcrowding, homelessness and unemployment (Feng et al., 2020; Sadr et al., 2020). In all cities, future climate-driven livelihood and economic stressors will aggravate these issues, making the challenge of sustaining viable cities greater than might otherwise be the case (Revi et al., 2014). And while more immediate management concerns arise from the effects of COVID19, the longer-term challenges from climate change remain and are expected to last far longer, probably well beyond the year 2100 for coastal cities affected by rising sea level.

Every large city faces climate-linked challenges that are unique, deriving from its location, its form and density, and from the activities that have sustained its recent development. Less obvious yet often of equal importance is a city's historical development, sometimes going back centuries, that have controlled the way in which it grew (Arden and Jawitz, 2019; Moreno, 2020). This is a function of both geography and of the oversight for such development, which will vary considerably depending on whether it takes place in, for instance, a capitalist or a socialist setting or a democratic or an autocratic one (Qian, 2015; Slaev et al., 2018). The historical decisions that affect social, economic and environmental conditions have set various courses of action which are manifested today through urban development, social norms, levels of social-ecological resilience, and dominant responses to

threats. This is referred to as path dependency and we argue in this study that an understanding of this is key to identifying sustainable futures for large cities, a point we illustrate by looking at five Asia-Pacific cities in diverse contexts.

The next section reviews the history of urbanization in the Asia-Pacific region and outlines the broad challenges to future urban sustainability therein. Then we discuss the phenomenon of path dependency and review its influence on planning for climate-linked adaptation. Then we present examples of five Asia-Pacific cities with contrasting development histories and climate exposure, and discuss past and planned approaches to adaptation.

ASIA-PACIFIC URBANIZATION AND ITS SUSTAINABILITY

Some of the world's earliest "cities" were established in East Asia (Renfrew and Liu, 2018). The constant land loss and developmental stresses imposed on coastal societies (and their complexification) during the period of postglacial sea-level rise (15,000–5,000 years ago in most places) ended about five thousand years ago, paving the way for the development of large/urban coastal settlements in many parts of the Asia-Pacific region (Day et al., 2007; Day et al., 2012). Lawler (2014) documents several recent discoveries of maritime sea routes and trading settlements that existed around 400 BCE.

Compared with many other parts of the world, the Asia-Pacific region has a disproportionately high number of large cities on the coast. These cities are located mostly around river-mouths and signify the importance of long-distance over-sea trade in the region, which intensified over the last 500 years. Examples include Manila (Philippines) that was the entrepôt in the "East Indies" favored by most European powers, Kochi (India) from which pepper and spices reached Europe, and Macau (China) through which Portuguese trade with China, Japan and the Malaccas (Indonesia) was driven for centuries (Malekandathil, 2013; Ebrey and Walthall, 2014). The nature of urbanization across the Asia-Pacific region followed a similar trend to that elsewhere in the world until about 150 years ago when ideologies started to influence development trajectories. Yet the legacy of sustained sea-trade is the proliferation of urban areas in the Asia-Pacific region that are increasingly prone to coastal climate hazards through both their geographic location and continued population growth (Chan et al., 2012; Smith et al., 2013).

Driven by an abundance of cheap energy, an acceleration in growth of urban populations in the Asia-Pacific region began around 1950 at which time less than 15% of its population was urban, a contrast with today when more than 50% of the region's population resides in urban areas, a trend projected to continue (Burger et al., 2018; Kundu et al., 2020). Yet the recency of urbanization varies within this region, with many East and Southeast Asian urban areas developing extremely rapidly from 1975 compared to Australia and New Zealand that experienced urbanization decades earlier (Guneralp et al., 2020). The delay (in some cases periodic decline) in urbanization in East and Southeast Asia has been attributed to the influence of totalitarian or communist regimes in several countries, particularly between the 1960s and 1980s. For example, the population of Cambodian cities declined by almost 60% when the Khmer Rouge took power in 1975 and forced urban populations into rural areas. Yet in Cambodia, since the transition towards democracy and neo-liberal ideologies, and the accompanying easing of internal mobility restrictions, rural to urban migration has soared. China has also experienced rapid urbanization over the past 40 years, facilitated by its transition towards a market economy, especially the rise of manufacturing, and centralized development initiatives (Friedmann, 2011; Chen et al., 2013). Similar trends have been experienced in the Pacific Islands; for example, Haberkorn (1992) found that 7% of Melanesia's population was urban in 1955, increasing to 20% by 1985, driven primarily by internal population mobility. Yet there is still considerable variation in urban population proportions in the Pacific, some countries like Fiji (where wage employment opportunities are comparatively high) having pre-COVID more than 50% of its people living in urban areas compared to countries like Samoa where just 18% of people live in urban areas (Keen and Connell, 2019).

Urbanization in many Asia-Pacific contexts has been sustained by the continued availability of cheap energy to power industry and production (Burger et al., 2018), which has left them with an outsized carbon footprint. As Lee comments, "the economic growth, exports, industrialization and urbanization of the developing countries in Southeast Asia have been achieved at the cost of increasing the carbon footprint of the region (implying) that the environmental policies of the export-led growth countries never have been effective so far since the nations have achieved their economic growth at the high cost of harming the environment" (Lee, 2019: 398).

With over 2.3 billion inhabitants, East and Southeast Asia is home to about 30% of the world's population. Yet while population growth is expected to continue until about 2050, it is also projected that the population of the region will have declined by 16% by 2100 (UN, 2019). In contrast, while Australia and New Zealand's combined population is only 30 million, it is expected to grow 63% by 2100. The rest of Oceania has a current population of 12 million people and is projected to grow by 117% within the same period. Overall, the proportion of urban dwellers in the Asia-Pacific is projected to remain stable or continue to grow (Attane and Barbieri, 2009).

Pre-COVID changes in the Asia-Pacific population are driven primarily by changes in fertility and mortality rates, although migration attributable to conflict and labor movements is an important factor, especially in terms of rural-urban migration For example, Myanmar has lost 1.3 million people owing to insecurity and conflict over the past decade while Bangladesh and the Philippines have lost 4.2 million and 1.2 million respectively as a result of temporary labor movements (UN, 2019). In contrast, Australia's population has been regularly increased by international migration. The long-term impacts of COVID19 on trends of population growth and decline in the Asia-Pacific region are as yet uncertain although there is mounting anecdotal evidence of urban-rural movement since the start of the pandemic, attributable to loss of wage employment in urban areas and the possibility of living more cheaply,

particularly on traditional lands, in rural areas (Panwar and Mishra, 2020).

Notwithstanding the current uncertainties regarding internal migration driven by COVID19, in several parts of the Asia-Pacific region, urbanization driven by economic and population growth, industrialization and rural depopulation has fuelled the rapid growth of "megacities" that are recognized as exhibiting particular challenges for future sustainability, especially in coastal locations where climate-change impacts have been (and are expected to be) particularly pronounced (Georgeson et al., 2016; Hinkel et al., 2018). For example, the liveability of China's megacities like Beijing and Shanghai has been challenged by recent heatwaves, their unprecedented severity and duration attributable to climate change, exacerbated by heat-island effects (Yu et al., 2018). In Metro Manila (Philippines), the increasing incidence and extent of urban flooding is attributable to both sea-level rise (amplified by land subsidence) and changing patterns of storminess, both likely results of climate change (Meerow, 2017; Doberstein et al., 2020).

All these region-specific impacts will be overprinted by global climate stressors, including shifts in the human temperature niche (Xu et al., 2020), more extreme heatwaves and wildfires (Mora et al., 2017; Robinne et al., 2018), stronger tropical cyclones and extreme precipitation events (Min et al., 2011; Power et al., 2017; Hinkel et al., 2018). It is also worth noting that coastal locations are expected to be disproportionately impacted by both global/regional climate stressors in the future, especially in low latitudes. This is not only because coastal livelihoods (and the infrastructure on which they depend) are more exposed along coastlines but also because many coastal cities in the low-latitude Asia-Pacific region have for several decades been experiencing comparatively complex challenges to their sustainability arising from their low-lying locations, such as exposure to extreme events associated with low-latitudes like tropical cyclones and heatwaves (Tessler et al., 2015; Day et al., 2018).

Climate change is showing signs of accelerating in the Asia-Pacific region and is expected to be a massive stressor on urban life by the end of this century, not least because global temperatures may average 2–4°C higher and global mean sea level may be over 1 m higher than today (IPCC, 2018; Horton et al., 2020). For many of the world's megacities, plans have already been drawn up to adapt to the clearest and most damaging effects of 21st-century climate change, ranging from the relocation of Jakarta (Indonesia) to the managed retreat of several North American cities (Carey, 2020).

Increased sensitivity to extreme events in coastal cities will be exacerbated not only by increases in population generally but also by an increasingly ageing population. Globally, in 2018, those aged 65 years and over outnumbered those aged under five for probably the first time in human history; from 2019 to 2050, the average life expectancy is likely to increase from 72.6 –77.1 years (UN, 2019). In the Asia-Pacific region, the proportion of people aged over 65 years is projected to increase in 2050 by 171–30.4% of the total population in East and South East Asia; by 80–28.6% of the total population in Australia and New Zealand; and by a massive 267–15.4% of the total population in the rest of Oceania (UN, 2019). This will not only place a massively increased strain on urban services but also a reduction in per capita economic activity (Tong et al., 2015).

To some degree, an increase in sensitivity of Asia-Pacific urban conurbations to extreme events may be offset by improvements in adaptive capacity, and there are several indicators showing that adaptive capacity has increased rapidly in this region over the past 50 years. For example, Attane and Barbiere (2009) show that literacy rates dramatically increased in East and Southeast Asia from 1980 to 2005 (e.g. in China, illiteracy dropped from 32.9% of the population to 11.8%); literacy makes communication easier, facilitates the spread of understanding, and can lead to adaptive actions that may be far more difficult to achieve when most stakeholders are non-literate. In addition, as Gallopín (2020) recently argued, future opportunities for urban sustainability are also afforded by the growing dissipation of urban functions, including long-distance supply of energy, the global sharing of information, and even the outsourced production of traditional urban materials. In such a situation, in which a city is losing entropy and having its environment disorganized, the question arises as to what a "sustainable city" might look like.

PATH DEPENDENCY AND ITS INFLUENCE ON ADAPTATION PLANNING

Since the 1970s, path dependency has been used by various disciplines to describe a constrained future option/s based on a previous decision/s. For example, Hohn and Schneider (1991), (p 111) show that "critical decisions, historical accidents, exogenous shocks and situational coincidences" shape a certain development pathway. In other words, path dependency refers to the reduction in the portfolio of options based on prior choices and conditions. When applied to adaptation to global change, investments in capital are made and thus promote continued investment to avoid loss of capital (Barnett and O'Neill, 2010). Contracts are established and need to be honored (Runhaar et al., 2012). Or more broadly, manipulative behaviors are adopted to maintain the status quo (Thomsen et al., 2012). Strategies to maintain the status quo, whether to avoid losses in capital investment or to appeal to social norms, lessen the probability of effective adaptation by creating adverse path dependencies "whereby each manipulative action increases social-ecological stress, reduces adaptive capacity, and necessitates continued manipulative actions in order to avoid changing the dominant social paradigm" (Thomsen et al., 2012, p 23). In contrast, systems approaches to adaptation that take both a broader and longer-term view of both the system under threat and the goals of adaptation, and guided by principles such as those outlined through a sustainable livelihoods lens (e.g. inclusivity, long-term poverty reduction, ecosystem stewardship, building of capacity and agency) are less likely to lead to path dependencies (Smith et al., 2013).

Diverse adaptive responses have been identified as a mechanism to reduce path dependency by broadening the range of available options using, for example, a combination of prevention, defense, mitigation, and adaptation strategies. Yet

FIGURE 1 | The Asia-Pacific region showing the five case study sites (bold) and other places mentioned in the text.

a study of flood risk management in Europe found that while path dependency was indeed high in countries where certain risk approaches had traditionally dominated (e.g. flood defense in the Netherlands), they also uncovered path dependency in countries with more diversified approaches (e.g. England and France) (Wiering et al., 2017). Additional considerations must therefore be taken into account to better understand path dependencies. For example, Stern (2006), (p 381) states that "individuals and firms behave habitually and in response to social customs and expectations. This leads to path dependency, which limits their responses to policies designed to raise efficiency". Shove (2010) adds that flexibility is not a usual trait of societal systems and that, only through the realization of vulnerability or a disastrous (trigger) event, is transformation possible.

Smith and Smith (2006) likewise highlight that committing to a learning framework may overcome path dependencies through institutionalizing continuous improvement for coastal sustainability. Furthermore, learning based on an understanding of the weight of the past, the push of the present, and the pull of the future (Inayatullah, 2008), combined with systems understanding, reduces the potential for decisions that will lead to path dependencies (Smith et al., 2013). Thus, a better understanding of these considerations for coastal cities in the Asia-Pacific region, which are exposed to significant coastal hazards, increasing both in intensity and frequency, is required if they are to continue to prosper.

CASE STUDIES

Here we briefly summaries the historical context, past approaches to adaptation, planned adaptations and adaptive capacity of five Asia-Pacific cities: Shanghai (China), Metro Manila (Philippines), Nadi (Fiji), Wellington (New Zealand) and Sydney (Australia). The case studies provide examples of the nature of path-dependency in various contexts. The case studies were selected to illustrate commonalities and differences in approaches in a range of geographical settings and cultural contexts throughout the region (**Figure 1**).

Shanghai, China

Shanghai is situated between the East China Sea, the Yangtze River Estuary, and Hangzhou Bay, bordering the Jiangsu and Zhejiang provinces (Yin et al., 2013). Since 1979, Shanghai has undergone rapid urban development, initiated by the government's "reform and opening-up policy" in 1978 and "opening Pudong new area to the world" in 1990 (Yin et al., 2011). Shanghai is now the largest economic center in China, where 85% of land is urbanized (housing a population of over 27 million people, with a population density of more than 2,059 people per square kilometer). Rapid population growth and rural-urban migration has driven significant land reclamation in Shanghai. Between 1949 and 2010, over 1,000 square kilometers of the coastal wetlands in the Yangtze Estuary was reclaimed (Mi et al., 2016).

Today, Shanghai city center is situated on the lowest floodplain of the city (Xian et al., 2018). It is vulnerable to flooding from both extreme events (e.g. typhoons) and sea-level rise (Wang et al., 2012). Land subsidence, both tectonic and compaction (resulting from groundwater extraction, high-rise construction and population growth), has contributed significantly to the rise in relative sea level. By 2070, it is anticipated that Shanghai will have more than 5.4 million people, and assets to the value of $1771 billion, exposed to coastal (river + sea) flooding (Xian et al., 2018).

The dominant approach to adaptation in Shanghai has been protection through the construction of sea walls (Bao et al., 2020); some of the earliest "hard" structures to prevent flooding were constructed in this region around 5,000 years ago (Liu et al., 2015). Today, Shanghai's developed coastline is protected by sea walls with a 200-years coastal flood return design. The implementation of protective measures has followed impacts of extreme events. For example, the "63 standard" for flood defense (specifying a minimum height for sea walls) was introduced following a 1962 flood event that destroyed 1,500 houses and killed hundreds of people. Later events saw the introduction of the "74 standard", and later still, the "84 standard" (requiring a design for the 1000-years flood level) which remains in use (Xian et al., 2018).

Despite these improvements, Wang et al. (2012) report that the existing 6-m-high flood-control walls are insufficient to address the combined effects of sea-level rise, land subsidence and storm surge. They estimate that by 2100, half of Shanghai will be regularly flooded and 48% of the length of current sea walls in Shanghai may be overtopped. Their findings are supported by Cheng and Chen (2017) who noted that raising the sea-wall standard from one-in-100-years flood height to one-in-200-years flood height was required to address risk from rising sea level combined with land subsidence.

The uptake of adaptation in response to sea-level rise has been slow (Cheng and Chen, 2017). This is in part attributed to limited forward planning in relation to climate risks (Xian et al., 2018). Despite this, Shanghai is implementing planned responses to address current climate risks, such as extreme flooding. For example, in 2016 Shanghai joined the Sponge City Initiative (Zevenbergen et al., 2018), an initiative with a target of 20% of urban areas absorbing, retaining, and reusing 70% of rainwater by 2020. By 2030, this percentage should increase to 80%. To achieve these targets, cities are investing in permeable pavements, artificial ponds and wetlands, and rain gardens to store excess rainfall. The required investments to achieve the ambitious targets are estimated at 100–150 million RMB per km^2 (16–24 million USD per km^2) in Shanghai.

Recognizing the exposure of its coastal cities, China has demonstrated significant capacity to rapidly implement reforms to address climate risks (as seen for example *via* the Sponge City initiative). Shanghai's rapid economic growth and significant economic position, and higher level of autonomy than other cities within provincial and central administrations, means it has the financial capacity and political commitment to implement large-scale infrastructure development. Furthermore, alignment between central and local governments allows for rapid consensual governmental decision-making yet there is little evidence of capacity for bottom-up and/or autonomous adaptation initiatives (Yin et al., 2011; Xian et al., 2018).

Metro Manila, Philippines

Located on the western side of Luzon Island, the sixteen cities (and one municipality) comprising Metro Manila are mostly coastal, either facing west to Manila Bay or east alongside the (lake named) Laguna de Bay; half occupy the narrow neck of land between the two. Metro Manila is currently home to some 12.8 million people, at least 700,000 of whom are informal settlers. Land reclamation for coastal defense unintentionally serves to provide additional land for informal settlements (Valenzuela et al., 2020).

The Philippines is one of the world's most disaster-exposed countries (De Leon and Pittock, 2017). In Metro Manila, the most common natural hazard is flooding, which typically occurs at times of unusually heavy rain, as is often associated with tropical cyclones (typhoons). Around half the area of Metro Manila floods during such events, which have become more severe (more common and enduring) in the 15 years. Typhoon Ondoy (or Ketsana, September 2009) involved 450 mm of rain in 12 h, a 40-year record (Abon et al., 2011); flood depths in parts of Metro Manila were around 7 m. More frequently, monsoon rains (habagat) are the main cause of yearly flooding here.

Strong typhoon winds also represent a distinct hazard, as do the landslides that most commonly affect those elevated, often steep land, parts of Metro Manila which are not commonly affected by flooding (Bankoff, 2003). The Manila (sea-floor) Trench that lies west of Luzon is the site of occasional earthquakes, some of which could generate tsunamis that would impact Manila (Ren and Liu, 2015). Sea-level rise is also expected to impact Metro Manila significantly, with estimated annual damage costs of up to US$6.3 billion; accounting for 98% of the expected sea-level rise induced damage costs for the entire country (McLeod et al., 2010). The effects of sea-level rise are worsened by human-induced land subsidence resulting from excessive extraction of groundwater (Rodolfo and Siringan, 2006).

In 1991, the national government decentralized fiscal and administrative responsibility to local governments. As a result, planning power was passed to city and municipal governments, where powerful land-holding families held strong political influence and privatized land use planning - a situation particularly evident in Metro Manilla (Mitchell and Laycock, 2019). Privatization has hampered environmental and hazard management efforts, whilst also increasing the divide between rich and poor (Mitchell and Laycock, 2019).

Like many rapidly-growing coastal cities in which relocation, even risk-informed planning, has been regarded as antithetic to development (and economic growth), Manila has tended to respond reactively to flooding events by building solid sea defenses (De Leon and Pittock, 2017). At the national level, the need to integrate climate change adaptation planning with disaster risk reduction has been recognized through, for example, an agreement between the Disaster Risk Reduction Management Council and the Climate Change Commission; and a People's Survival Fund (established in 2012) to provide long-term financing to local government and communities to implement climate change adaptation projects. Yet De Leon and Pittock (2017) note that a long-term and integrated approach to planning for climate change and natural hazard risk is yet to be developed, with a focus on technological, short-term, project-based approaches: a situation common when adaptation and disaster management responses are led by donor partners, as is the case in the Philippines.

The favoring of short-term incremental (rather than longer-term transformational) interventions for climate-change adaptation in Metro Manila is also explained by "highly bonded social capital" reinforced by a culture of awareness and decision-making that is siloed and incompletely informed (Laycock and Mitchell, 2019).

It has become clear that in Metro Manila the "sole reliance on traditional 'hard' engineering or structural measures is now insufficient for flood hazard control" (Mercado et al., 2020: 1) implying that relocation of people and infrastructure from the most exposed areas is increasingly recognized as the only long-term sustainable solution. Relocations have previously occurred but most have been temporary, displaced residents returning to their former abodes once they become habitable again. Many residents favor building upwards but most do not entertain resettlement beyond the city; in a recent survey, "no interviewee identified any possible solutions to the political challenges for resettlement in Manila" (Tadgell et al., 2017: 456).

Yet there is a growing awareness of a need for bold high-level strategic interventions in Metro Manila to build its resilience, something which requires not merely on-ground action but also "incremental shifts to existing social capital" (Laycock and Mitchell, 2019: 47), in other words developing a will to transform livelihoods. To this end, "managed retreat" has been repeatedly proposed in Metro Manila although several barriers–including land availability, livelihood loss, and corruption–continue to hinder its implementation (Doberstein et al., 2020).

National challenges involved in sustainable economic development are well illustrated for the Philippines, given its rapidly growing economy (pre-COVID19) and its escalating exposure to disaster. For example, the Philippines was the fastest-growing economy in Asia in 2015 but also ranked 33rd out of 48 countries in the region in terms of water security, something that reflects the country's "inability to give water security the same level of importance as economic development" (Lee et al., 2020: 1). This is a common situation, especially in Asia-Pacific cities, exacerbated in the case of Metro Manila by both droughts associated with El Niño events and an outdated (inadequately-maintained) water-supply infrastructure.

At a city level, several authors have proposed that the major cause of flood management in Metro Manila is the institutional governance framework, specifically the absence of a governing body with sufficient power to overrule competing (economic) interests to develop and direct appropriate disaster risk reduction management plans (Laycock and Mitchell, 2019; UNDRR, 2019). Such an impotency of governance, which is clearly displayed in the aftermath of disasters such as Typhoon Haiyan (or Yolanda, November 2013), also points to the inability of national government to translate policy into resilience-building at the community level (Walch, 2018).

Nadi, Fiji Islands

Nadi is located on a coastal delta-edge on the west coast of Viti Levu, the largest island in the Fiji archipelago (Southwest Pacific), and grew in the early decades of the 20th century as an entrepôt for agricultural exports from the fertile Nadi River Basin and imports to sustain the area's growth and importance to the colonial government. Nadi was formally declared a township in 1947 and is currently home to around 45,000 people. Today, Nadi is Fiji's principal tourism hub, a commercial, recreational and light-manufacturing center sustained largely by the 900,000 visitors each year (pre-COVID19) who pass through the adjacent Nadi International Airport. Although Nadi lies within the Viti Levu rainshadow, it receives an average 1900 mm annually, mostly in summer and commonly associated with tropical cyclones.

Much of Nadi is flood-prone, a result of combined delta subsidence and sea-level rise currently around 4 mm/year (Nunn, 2013) and it seems clear that the nature and pace of recent coastal developments here is incompatible with the accelerating rate of climate change (Bernard and Cook, 2015; Chandra and Gaganis, 2016; Nerem and Fasullo, 2019). In particular, the subsidence-enhanced effects of sea-level rise on the Nadi fringe and the projected increase in average tropical-cyclone strength both signal the need for transformative adaptation of functionality and production in the Nadi area, as elsewhere in the Pacific Islands region (Nunn and McNamara, 2019).

Most of the adaptive measures undertaken in the Nadi area to reduce flooding in the past have been predicated on the belief that the problems are principally caused by poor land and urban management–and that these problems can therefore be corrected by improving practice. While this is consistent with the culturally-grounded short-term outlook common in several Pacific Island societies (Nunn, 2009), it is also a response to the belief that effective adaptation is costly and that it should be avoided for that reason; in other words, cash is scarce and should not generally be allocated to non-revenue generating activities. So as in many poorer contexts elsewhere in the world, the response in Nadi to flooding has been minimalist, low-cost and incremental (Kates et al., 2012).

In the belief that unspecified deforestation of the hinterland (which was actually denuded more than a century ago) caused infilling of lowland river channels, diesel dredgers have regularly been deployed without any clear understanding of sediment dynamics and the effects of sea-level rise on this (Nunn, 2013). In the belief that the town drainage (storm runoff) system was not functioning properly, a major revitalization was undertaken (McNamara, 2013). And coastal (tourism) developers who cleared mangroves, exposing soft-sediment coasts in Nadi Bay to wave erosion, to reclaim land have often had to spend significant funds to construct unsightly sea defenses (Bernard and Cook, 2015).

The usual practice of Pacific Island governments, with commonly little discretionary funding, is to appeal to donors for finance to underwrite the costs of climate-change adaptation (Nunn and Kumar, 2019). A good example of this in Nadi has been an ambitious scheme to divert the course of the lower Nadi River, moving its mouth several kilometers further away from Nadi Town. The Government of Japan, a major donor partner of Fiji, undertook studies that suggested this would significantly reduce flooding of Nadi Town; the reasons for this deduction are unclear but the likely assumption is that terrestrial sediment

accumulation in lowland river channels is the main cause of recent increases in flood frequency, magnitude and extent. This is unfortunate, especially as there is compelling evidence that a sea-level rise of at least 4 mm/year is likely to be the principal cause of increased flooding in Nadi. The Japanese Government initially promised to fund the river-mouth diversion project but have recently pulled back from doing so. The only effective and sustainable solution is to relocate Nadi Town, at least its lowest and most vulnerable parts (Nunn and Kumar, 2019).

Among the independent island nations of the Pacific, there is little appetite for costly disruptive transformational adaptation to future climate change of a kind that academics and others are increasing recognizing as necessary to avoid far more costly and disruptive incremental adaptation (Klöck and Nunn, 2019; Nunn and Kumar, 2019; Nunn and McNamara, 2019).

In the case of Nadi Town, a preference for continued *in-situ* adaptation is still expressed, with year-by-year repairs made to infrastructure and businesses on the unspoken assumption that the situation will eventually get better. This attitude can be ascribed to pragmatic denialism but in a Pacific island context it is also important to acknowledge the role of faith-based beliefs (Nunn et al., 2016). Faith underlies national, community and individual self-belief across the Pacific region and has commonly been cited as a reason for what outsiders invariably perceive as "climate inaction"; in several Pacific Island nations–climate projections involving continued sea-level rise are often denied on the grounds they run contrary to God's promise not to flood the earth anew (Kempf, 2017). New approaches meshing religious beliefs with science-based projections hold considerable promise (Fair, 2018).

In urban centers like Nadi, it is likely a tipping point will be reached at some future time when, perhaps as a result of the lowest part of Nadi being permanently underwater for several months, it will be realized by authorities (and their donor partners) that *in-situ* adaptation is no longer a rational future option. This will force transformational adaptation, in this case the relocation of key functions to the Nadi hinterland (Nunn and Kumar, 2019; Nunn and McNamara, 2019).

Urban centers like Nadi that are facing growing and profound challenges from climate change have little inherent capacity to counter associated risks, just as the government that oversees Nadi's development has insufficient resources of its own to solve these challenges. Costly interventions must be funded by Fiji's donor partners or the international community, an approach that in the past has seen donor agendas and understandings privileged, often to the detriment of the effectiveness and sustainability of interventions (Nunn et al., 2020).

Yet countries like Fiji have a degree of innate resilience that can help communities–and even urban centers like Nadi–cope with climate change and disasters (Korovulavula et al., 2019; Nunn and Campbell, 2020). So it is conceivable that community-based organizations to which various groups of Nadi residents belong will drive transformational adaptation in the future.

Wellington, New Zealand

Wellington was settled by Māori people prior to the 12th century and colonialized by Europeans from 1840. In 1865, Wellington became New Zealand's capital, facilitating its growth as a commercial and administrative center. Wellington is currently the second largest city of New Zealand and the Wellington region has a population of over 500,000 people.

Wellington's development has been markedly shaped by its geography. Situated on the southern tip of New Zealand's North Island, the waters of Cook Strait to the east and south, and mountain ranges to the west and north, limit the availability of flat land, most of which was developed by 1911. For almost a century until the demise of manufacturing, the harbor was the heart of the city, but became a redundant waterfront in the 1970s and early 1980s. With the loss of manufacturing employment, growth has been in the financial services sector and, despite the growing dominance of the business sector in Auckland, Wellington retains its role as a commercial center as well as the seat of national government in New Zealand.

New Zealand lies on the boundary between the Indo-Australian and Pacific tectonic plates; and the Wellington region is crossed by a number of major faults, including the Wairarapa, Wellington and Ohariu faults. Consequently, the region has been subject to a number of large earthquakes, including an 8.2 magnitude quake in 1855, which damaged the city and uplifted parts of the harbor, and in November 2016 when a 7.8 magnitude quake caused damage to buildings throughout the region (Kurashimo et al., 2015). Tsunami risk is high, as is flood risk. In addition, the region is exposed to storms, with New Zealand lying in the path of the strong westerly airflow known as the roaring forties. In addition, the North and South Island mountain ranges funnel winds through the Cook Strait, which results in extreme wind conditions. Projections suggest increased risk to coastal roads and infrastructure from coastal erosion and inundation, increased storminess and sea-level rise (Reisinger et al., 2014; Cagigal et al., 2020).

Wellington has historically adopted hard defense options to respond to sea-level rise and other coastal hazards. Pressure placed on local governments by developers or private property owners is the principal driver for this response, with councils having capitulated to the protection of private property in the face of coastal inundation. This has led to a "legacy of development, including long-lived infrastructure, exposed to increasing climate risks that will create ongoing costs and liabilities for councils" (Manning et al., 2015, p 588).

Having regard for the effects of climate change is now a statutory requirement in New Zealand, one primarily overseen by local government. Local government action is informed by a National Coastal Policy Statement and documents describing risk-based approaches to respond to sea-level rise and flood risk. Yet there have been variable responses across local governments in the country (Lawrence et al., 2019).

In August 2019, the Greater Wellington Council joined a number of local and regional government authorities in New Zealand in declaring a "Climate Emergency" (Davidson et al., 2020). The resultant Action Plan focuses on supporting locally-driven and locally-relevant adaptation plans, emphasizing a community-driven approach to plan adaptation responses (GWRC, 2020). Several current community-based adaptation planning initiatives are underway. For example, the Common

Unity Project Aotearoa (CUPA) initiative in Te Awa Kairangi/ Lower Hutt encourages participation from those who have not traditionally been included in decision-making processes and also focuses on broader community development and wellbeing initiatives (Simon et al., 2020).

Another example are the community-led adaptation plans developed for Makara Beach in the Greater Wellington region. Over a 6-month period, community representatives worked together with local council, guided by technical experts, to develop adaptation pathway plans. Whilst reportedly considering a range of adaptation options (including managed retreat and defense structures), the plans adopt a business-as-usual approach, advocating for sediment deposition in the short-medium term, followed by seawalls to address longer-term impacts. Thus, despite a policy focus and strong advocacy for managed retreat in the longer term, very few examples of managed retreat have been successfully implemented in New Zealand (Hayward, 2008). Furthermore, studies into community preferences have found a significant preference for seawalls or large rocks and almost no appetite for managed retreat.

At the countrywide scale, in a report on adaptation action across sectors, the National Adaptation Technical Working Group identified some examples of proactive adaptation action. Those identified occurred in circumstances of high exposure and large inaction costs, and typically involved investment in flood risk and coastal hazard management, and some transport and food-security projects (Bond and Barth, 2020; Cradock-Henry et al., 2020; Paulik et al., 2020).

Overall, there is little evidence in Wellington and other New Zealand coastal cities of proactive or transformational action to reduce climate risk, similar to elsewhere (Hinkel et al., 2018). In most cases, action has been reactive and part of a sector's usual (path-dependent) natural hazard management response after extreme events occur, rather than being proactive and undertaken with a long-term transformational perspective. The adoption of hard defense options to respond to sea-level rise in the near term also constricts the ability to transition towards a flexible adaptation pathways approach. In addition, attempts to implement spatially sensitive setback lines based on risk, together with signals in some areas that retreat could be inevitable (following a pathways approach), have led to opposition and retraction (Manning et al., 2015). Yet the enactment of managed retreat in the aftermath of the Christchurch earthquakes provides an example to draw on for future climate-forced retreat from vulnerable coasts in New Zealand (Hoang and Noy, 2020; Nguyen, 2020).

Future adaptation of Wellington is constrained primarily by its geography. The natural landscape not only predisposes Wellington to a number of extreme hazards (such as earthquakes, storms and floods) but it limits accommodation and other possible response options through the comparative lack of flat (developable) land. While the decentralized approach to adaptation planning in New Zealand provides opportunities for innovation that are place-based and cognizant of the local context, there is concurrently a reliance on constrained local government resources for implementation. Limited budgets together with limited public engagement with climate-change adaptation has resulted in this being a low priority for some local governments in New Zealand (Archie et al., 2018).

Sydney, Australia

Sydney is the most populous city in Australia with over five million inhabitants, widely recognized for the iconic Sydney Harbor (Davies and Wright, 2014). Sydney was first inhabited by Aboriginal Australians over 20,000 years ago and then occupied by European settlers in the late 18th century. Over the past two centuries, large areas of mangrove and saltmarsh have been cleared for commercial, residential and recreational purposes (Rogers et al., 2019). More recently, increasing land scarcity in the Sydney region due to population growth, topographic constraints, and the presence of surrounding national parks, has led to significant urban infill and redevelopment of coastal areas, such as the AU$6b Barangaroo mixed-use residential development close to the centre of the CBD.

While in the past, the coast of Sydney was by default the most active interface between land dwellers and sea travelers, today its coast forms an integral part of the city's appeal; its beaches are a draw card for recreation and tourism. While the New South Wales State and Australian national governments play a role in managing the Sydney coastal zone, the majority of routine management activities rests with local governments. Fifteen coastal local governments collectively formed the Sydney Coastal Councils Group in 1989 as an advocacy and collaboration collective to further coastal management outcomes for the Sydney region although, after subsequent local government amalgamations and other factors, only nine members now remain.

The coast of Sydney is subject to a range of hazards that are projected to intensify with climate change, in particular sea-level rise and associated tidal inundation, storm surge, flooding, and coastal erosion (Hague et al., 2020). For example, vulnerability to flooding from minor coastal inundation has increased fivefold since 1914. The areas of greatest exposure to sea-level rise are found around the low-lying areas of Botany Bay as well as Sydney's northern beaches (Preston et al., 2008). Coastal erosion is a significant issue and as Bonyhady (2010), p 85) notes, "inappropriate subdivisions (have) . . . resulted in many houses and some high rises being built not just on the dunes but on the beach", exposing them to coastal erosion risk. A recent example of extreme coastal erosion occurred in Collaroy on Sydney's northern beaches in 2016, causing extensive destruction to property (Mortlock et al., 2017).

Hard protection approaches have historically been adopted in response to flooding, inundation and erosion. In Sydney Harbor, seawalls armor more than 50% of the shoreline (Bulleri and Chapman, 2010). Local governments responsible for managing coastal areas and associated risks have been subject to pressure from erosion-impacted coastal residents to protect their homes through the installation of armoring structures (O'Donnell, 2016).

In 2008, the Sydney Coastal Councils Group identified the need for practice-relevant research to build capacity to understand and address climate vulnerability (Measham et al.,

2011). A three-phase project was implemented, involving an extensive mapping process to visualize relative vulnerability (Preston et al., 2008); systems analysis of vulnerability interdependencies and council responses (Smith et al., 2008b); and case studies focusing on key adaptation barriers (Smith et al., 2008a). As a result, participating local governments received Australian Government funding to develop local adaptation plans.

In 2018, the State Government adopted the Coastal Management Act 2016 which required that by 2021 all coastal local governments would have developed Coastal Management Plans (CMPs) as defined in the Act and supporting policies. The selection of management responses, whether hard protection or other, was to be defined by the CMP process, with the State Environmental Planning Policy specifying councils are to be "reasonably satisfied" with the outcomes of their adaptation choices. This includes, for example, the potential for adverse impacts of protection structures on adjoining sections of coast.

The Greater Sydney Harbor region is currently undertaking a CMP and, at the time of writing, had completed the scoping study, which identified jurisdictional ambiguity as a major challenge to coastal management (Donaldson et al., 2018): a good example of the difficulties that bounded jurisdictions of any size have coping with transboundary issues like climate change (Barnes, 2017; Booth et al., 2020). Furthermore, it was noted that action along the coastal and estuarine margins was occurring in a localized manner through individual plans and initiatives, with limited integration (Donaldson et al., 2018). By establishing a Steering Committee and Partners Group, the CMP seeks to promote a whole-of-government partnership and a collaborative governance framework for managing Sydney Harbor.

The key incentive for such collaboration appears to be cost-sharing more so than integrated coastal planning. Other Sydney coastal councils (such as the Northern Beaches Council) will also embark on the development of CMPs as part of the updated legislative requirements. These plans will set the basis for adaptation planning over the coming years. Whether they promote a transition from the dominant hard protection approach to managing coastal risk or towards "risk-weighted decision pathways", as advocated by Preston et al. (2013), in which different portfolios of adaptation options are planned and implemented over time depending on the perceived risk, is yet to be seen.

Smith et al. (2008a) identified the following local government adaptive capacity constraints in reference to coastal management of Sydney:

- Local community conditions/characteristics: variable human capital; diverse perceptions; a disconnection between attitudes and behavior; and limited community education;
- The nature of existing infrastructure: aging infrastructure; existing non-climate related vulnerabilities; lack of council control over infrastructure; community expectations regarding infrastructure; and
- Planning and decision-making processes: jurisdictional overlaps; planning inconsistencies; political pressure; resources for planning; and legacies and trade-offs.

In 2015, despite controversy and challenges by many local authorities, the State Government undertook a process of council amalgamations in an effort to deliver efficiencies by scale. While amalgamation has delivered some adaptation benefits through economies of scale and cross-subsidization of adaptation initiatives, it may also lead to a disconnect between local decision-making and a depletion of local ownership over adaptation efforts as a result.

Capacity is not uniform across Sydney's local government areas. In a review of their adaptive capacity to respond to coastal impacts, the well-resourced coastal local governments in central Sydney were found to have the highest capacity to cope with their exposure and sensitivity to coastal hazards (Preston et al., 2008). Capacity was notably less developed in other areas of Sydney. For example, the local governments surrounding Botany Bay generally had lower levels of adaptive capacity, suggesting management of coastal hazards in these areas may be a greater challenge. In addition to local collaborations, some local governments have also connected globally. For example, the City of Sydney joined the C40 global network and 100 Resilient Cities program.

Local governments also face a dilemma in that there is guidance issued by the New South Wales State Government regarding projected coastal hazards (e.g. the Draft Sea Level Rise Policy Statement released in 2009), which potentially makes them responsible for development approval decisions yet unsupported financially to defend any development rejection decision brought by a developer in the Land and Environment Court (Sheehan et al., 2018). This is an example of an increasingly common situation in which local actors are becoming more aware of their legal exposure in climate-change decision-making yet are forced to act within a broader (State or National/Federal) context that often militates against effective local action (Kennedy et al., 2010; Cseh, 2019).

PATH DEPENDENCY AND ADAPTATION: LOOKING TO THE FUTURE

The five case studies discussed above demonstrate the nature of path dependency in various contexts. **Table 1** summarizes the diversity of situations and the overriding importance of path dependency to explain recent and planned future actions to combat the effects of climate change.

One common observation is that despite advocacy for transformative adaptation responses, such as managed retreat, within some of the case study cities (e.g. Sydney and Wellington) and within the research community more broadly, the futures for all five cities favor protection, which is the most common recent (past) approach. For example, Hinkel et al. (2018) argue that the majority of coastal cities globally are developing along trajectories that will not allow sustainable adaptation to expected future sea-level rise. Some recent studies suggest sea level may be 1.65 m

TABLE 1 | Comparison of case studies.

	Shanghai	Metro Manila	Nadi	Wellington	Sydney
Coastal hazards	Storm surge, flooding, sea-level rise (amplified by subsidence)	Flooding, sea-level rise (amplified by subsidence), typhoons	Sea-level rise (amplified by subsidence), flooding	Tsunami, sea-level rise	Erosion, sea-level rise
Primary adaptation driver	Extreme events	Extreme events (capacity-linked default)	Extreme events	Extreme events (statutory requirements)	Extreme events (risk to private property)
Dominant Adaptation Approach (Past)	Protect	Protect	Protect and accommodate	Protect	Protect and accommodate
Proposed Adaptation Approach (Future)	Protect and accommodate	Protect, accommodate and retreat	Protect and accommodate	Community-led adaptation planning; however, focus remains on protection in the long-term despite advocacy for flexible adaptation pathways	Protect and accommodate
Capacity Constraints	Limited bottom-up or autonomous adaptation	Financial resources and awareness, competing priorities (like water), geographical constraints	Financial and awareness constraints; (perceived) dependence on donor funding	Geographically constrained	Variable capacity across local governments; reduced subsidiarity due to local government amalgamations
Capacity Resources	Top-down authority in decision-making; financial resources	Growing bottom-up awareness and autonomous adaptation; non-government activities	Growing awareness of need for transformational adaptation; generosity of donors	Decentralised and participatory approach to adaptation planning	Economies of scale due to amalgamation
Path Dependencies	History of engineering protection and continuing technocentric worldview	History of (largely reactive) protection; preferential focus on economic growth and accommodating growing population	History of accommodation, low awareness of long-term nature of change	Constrained topography and history of successive engineering protection works	Private property rights and history of successive engineering protection works

(above the 1986–2005 baseline) by 2100 (Horton et al., 2020), a figure that may well be higher in most (if not all) of our case-study cities because of land subsidence, both natural and human-induced. If this projection were not sufficiently persuasive, then the consensus that sea level will continue rising beyond 2100, perhaps reaching over 5 m above today's level by the year 2300 (Horton et al., 2020), points to a future for most of these coastal cities that is not consistent with their current development trajectories.

Factoring into this, especially in poorer contexts (like Nadi and Manila), is the lack of sufficient funds to enable transformational rather than incremental adaptation. It is clearly much easier for local (and national) governments to fund the construction or repair of sea defenses than it is for them to relocate vulnerable communities, although clearly the point will be reached–as it has with Jakarta (Indonesia)—where wholesale relocation is acknowledged as unavoidable and plans are drawn up to enable this (Shimamura and Mizunoya, 2020; Van de Vuurst and Escobar, 2020).

It is clearly most difficult to drive transformative adaptation of this kind in democracies, especially those in which key decision-makers are elected every few years and there are grassroots movements that either deny or actively resist the need for such adaptation, as in Sydney and Wellington. While mega-engineering projects are obviously funded and undertaken in countries like Australia and New Zealand, they are in the name of "progress" and "economic growth" rather than anything like "adaptation" that might be perceived negatively by the electorate. In contrast, in situations like Manila and Shanghai, national top-down decision-making in the recent past has been enduring, effective and often transformative; examples from the Philippines include New Clark City, which will accommodate 1.2 million people from largely vulnerable coastal areas, and in China the Three Gorges Dam and South-North Water Transfer Project (Ran et al., 2020; Rogers et al., 2020). Then in countries like the Fiji Islands, where there are recent trends of growing dependency on external (donor) funding for adaptation, it is likely that over the next 2 decades, adaptation in coastal cities like Nadi will be largely reactive, unplanned and autonomous, as donor funds are redirected towards their domestic adaptation (Nunn and Kumar, 2019).

Urban settlements are comparatively recent developments, megacities essentially a late 20th century phenomenon, so the nature of planning therein has no great experiential legacy. In fact, urban settlements were created so that particular groups of people might advantage themselves; the linking of economic growth to both population and spatial growth was once the principal reasons for cities to exist (Berry, 2007). In many instances, the dangers of agendas of growth being foregrounded to the exclusion of those of sustainability have been clearly shown; one example is that of the Japanese city of Kobe, the unsustainably rapid growth of which was abruptly halted by the 1995 earthquake, its human and economic effects amplified by the lack of planned development and high population densities (Matsuyama et al., 2015). While there are numerous examples of repeated failures within urban settlements

in relation to risk management, there continues to be little emphasis on adaptive management, and more specifically learning (Smith and Smith, 2006), to inform decisions through a cycle of continuous and informed improvement. For example, Jacobson et al. (2014) in a survey of Australian coastal managers, found that fewer than half of respondents (42%) used monitoring and evaluation to inform adaptive management, and less than one third (32%) for assessing management effectiveness.

The dominance of "protect" approaches to adaptation in coastal cities is an expression of their inhabitants' desire to maintain their city's original purpose: that of growing prosperity. This might explain the reluctance of such cities to embrace "retreat" and other transformational solutions for these imply a failure of function. They involve an admission of error: what was once promised is no longer achievable. And while such admissions are likely to become widespread over the next few decades, in particular as humanity slowly realizes it has no choice but to adapt transformatively to future long-term climate-driven stressors, they are currently hindering optimal responses to current stressors (Ribeiro and Goncalves, 2019; Matyas, 2020).

CONCLUSION

It is clear that path dependency is a powerful influence on recent and planned (future) adaptation to climate change (and other livelihood stressors) in coastal cities across the Asia-Pacific region. Our analysis suggests that while almost every coastal city (including all five case studies) in this region is handicapped in their planning by their historical favoring of "protect" responses, it is those cities where decision-makers are regularly elected (rather than appointed) that may be slowest to embrace more transformative responses because of popular resistance to the disruptive effects of these. Yet this may be due to neoliberal market pressures, entrenched and perverse institutional arrangements, and the influence of elites, rather than democratic processes per se.

For the future, it must be hoped that a growing awareness of both the severity and immediacy of climate change, as well as the likelihood of irreversible multi-century future sea-level rise, will inform not simply the agendas of key government decision-makers but also the minds of all urban dwellers so that transformative adaptation–like the trailblazing relocation of Jakarta–will become more widely adopted.

Yet at the same time, it seems clear that most large coastal cities in the Asia-Pacific region would be experiencing challenges around sustainability even were the climate not changing and aggravating these challenges. Adaptation to climate change may not therefore go hand in hand with the attainment of sustainability of cities in this region or elsewhere, requiring that current and recent trends of urban development in coastal locations be examined holistically to identify interventions that will sustain future urban functionality and livelihoods, even perhaps divorced from place.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

PN and TS conceived the paper and contributed most parts. CE-B contributed three case studies and to the entire article.

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Transdisciplinary, Co-Designed and Adaptive Management for the Sustainable Development of Rongcheng, a Coastal City in China in the Context of Human Activities and Climate Change

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Half the population of China live in coastal zones where 70% of large cities are also located. Intensive human activities pose significant environmental and ecological hazards to these cities that are already vulnerable to natural hazards and climate change. The sustainable development of coastal cities is thus both a national and international issue. Rongcheng is a typical coastal city in east China. It is a national marine ranch demonstration area that is subjected to multi-stressors from human activities and climate change. The dominant economic sectors include aquaculture and fisheries, agriculture, shipping and tourism. A multitude of resulting pressures come mainly from intensified human activities, such as intensive aquaculture, overfishing, industrial pollutants, agricultural runoff, land reclamation and port expansion. In addition, Rongcheng is also facing exogenic pressures from extreme climate events such as intensified storms, storm surges, droughts and sea ice. A growing awareness of these problems brought together a trans-disciplinary group from local government, research institutions, local practitioners and coastal representatives to jointly explore and co-design adaptive coastal management options. In this transdisciplinary study, a social-ecological analysis based on a combination of the Systems Approach Framework and the Drivers-Pressures-States-Impacts-Responses framework was used to analyze and formulate an adaptive management plan for the sustainability of Rongcheng. More than 40 stakeholders including government, companies, civil society and institutions participated in the study through questionnaires and on-site meetings. A statistical analysis of the results identified urgent issues impeding the sustainable development of Rongcheng. The issues identified were poorly regulated aquaculture, loss of shoreline, and the decline of seagrass and cultural heritage. The study identified management options and measures, some of which were adopted by the local government in a co-designed

management plan. The measures included upgrading of aquaculture industry, habitat conservation and restoration, and the development of cultural tourism. Another outcome was the increased knowledge exchange between stakeholders to inform management, policy, and decision making, as well as raised awareness of vulnerability to natural hazards and climate change. The success of this case study provides a reference for the adaptive management of other coastal cities and their sustainable development in a changing climate.

Keywords: coastal city, human activity, DPSIR, climate change, sustainable development, transdisciplinary adaptive management, social-ecological systems

INTRODUCTION

One-third of the world's population lives within 100 km of the coastline, and 62% of cities with a population of more than 8 million are in coastal areas (Stephenson et al., 2010). In China, more than 70% of large cities and 50% of the population are concentrated in the eastern and southern coastal areas (Wang et al., 2012; You, 2019). Since the industrial revolution when Greenhouse Gas (GHG) emissions increased dramatically, the global climate system has been experiencing significant changes characterized by global warming. An increase in temperature is posing huge challenges such as sea level rise (SLR), sea surface temperature (SST) rise, storm surges, sea water intrusion and coastal erosion to the coastal cities. Moreover, climate change is compounded by past and present patterns of unsustainable development that have degraded coastal ecosystems and increased social vulnerability. Furthermore, climate change impacts like SLR are increasing the intensity and frequency of some hydro-meteorological events, such as extreme sea-level-related events. Recently, the WGI report of IPCC (2021) outlined the physical scientific basis of climate change, including the latest projections about SLR. The IPCC SROCC report outlined details of the challenges faced by coastal cities (Oppenheimer et al., 2019). In this climate change context, the pressures originating from high-intensity human activities such as industrialization, agricultural intensification, coastal land reclamation, and rapid urbanization are changing the coastal ecosystems, especially in developing countries (Major et al., 2018), such as China.

The global scientific community recognizes the importance of the sustainability of the oceans and the United Nations Educational, Scientific and Cultural Organization (UNESCO) has launched the initiative "The Decade of Ocean Science for Sustainable Development (2021–2030)". There is also global awareness of threats and risks to coastal cities due to climate change and human activities. Future Earth Coasts[1] is undertaking coastal zone research focusing on trans-disciplinary adaptive strategies that integrate excellent science, effective governance, social and cultural adaptations, and raising public awareness of coastal risks (Future Earth Coasts, 2018a; Future Earth Coasts, 2018b). Future Earth Coasts brings together an international group of scholars, including the co-authors of this article, who explore how to translate the above aspirations into practical reality through a series of case studies.

Coastal city responses to climate change and anthropogenic stressors have been extensively studied to explore various approaches to support sustainable development (Newton et al., 2016; de Alencar et al., 2020). Adaptation strategies to climate change rely on excellent science, as well as local culture, social networks, economic and political systems (Mea et al., 2016; Sorensen et al., 2018). A transdisciplinary, co-designed, adaptive management framework can contribute positively to the sustainable development of a coastal city, in the context of climate change and human activities, by addressing stakeholder issues and perspectives (Semeoshenkova et al., 2017; Berninsone et al., 2018).

Adaptive-management frameworks can be used to analyze prominent local issues of coastal social-ecological systems (Binder et al., 2013). They depend on a co-learning process that begins with stakeholder engagement and concludes with the implemention of practical management actions (Frohlich et al., 2019). Various studies and research approaches have developed trans-disciplinary adaptive strategies (Chiang et al., 2014; Mansur et al., 2018; de Alencar et al., 2020). However, transdisciplinary, co-designed, adaptive management is a relatively new approach, with few examples in China.

In this study, Rongcheng, a typical coastal city in East China was selected as a case study, to explore how transdisciplinary, co-designed and adaptive management could support sustainable development, especially the response to coastal hazards in the context of human activities and climate change. Two adaptive management frameworks, Systems Approach Framework (SAF) and Drivers-Pressures-States-Impacts-Responses (DPSIR) were used in combination to 1) map the stakeholders engaged in the study; 2) identify and analyze the key issues impeding the sustainable development of Rongcheng; 3) formulate an adaptive management plan for Rongcheng City. This provides a reference case study on the adaptive management and sustainable development efforts by other coastal cities in a changing climate.

This study addressed the following research questions:

(i) What are the main hazards for the sustainable development of Rongcheng from the perspective of scientists?

[1]Formally the Land-Ocean Interactions in the Coastal Zone (LOICZ) project of the former International Geosphere Biosphere Programme (IGBP) and the International Human Dimensions Programme (IHDP).

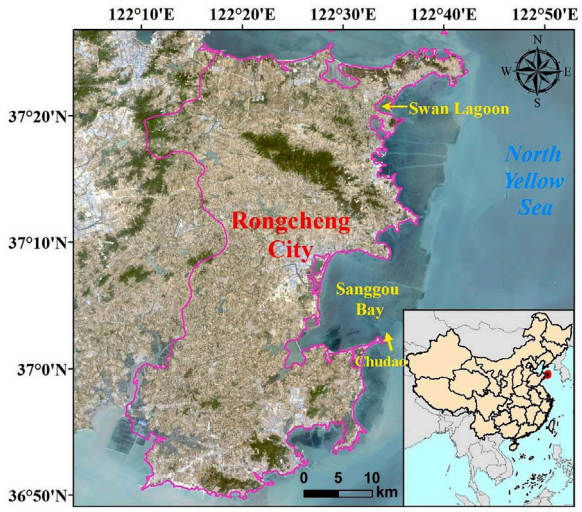

FIGURE 1 | Location of Rongcheng city on the coast of China.

(ii) Who are the interested parties with respect to the sustainable development of Rongcheng?
(iii) What are the main issues for the sustainable development of Rongcheng from the perspective of the local, interested parties?
(iv) What is the willingness to engage in participatory processes as a stakeholder?
(v) Who are relevant stakeholders corresponding to the main identified issues?
(vi) What are the management options to address these issues?
(vii) Does the transdisciplinary approach contribute knowledge that is useful to decision-makers?
(viii) Does the approach raise awareness of vulnerability to natural hazards and climate change?
(ix) Can this approach be useful for future-proofing coastal cities in China?

MATERIALS AND METHODS

Study Area

Rongcheng City[2] district is located on the easternmost tip of Shandong Peninsula, China (see **Figure 1**), facing the Yellow Sea on its north, east and south sides with a coastline of 500 km. The city district has a land area of 1,526 km^2, with the jurisdiction over 26 towns, 920 administrative villages, and a total population of 660,000. The terrain slopes from northwest to southeast, with an average elevation of 25 m. There are 102 rivers in the city, all of which have intermittent flows, following seasonal rains. The climate here is warm, humid, and influenced by monsoons. Surrounded by the sea on three sides, the city climate is significantly regulated by the ocean, with the characteristics of maritime climate. There are 10 bays, 10 natural bathing beaches, 115 islands and 100 km^2 of tidal flat along the shoreline. Rongcheng possesses numerous natural and cultural landscapes, including the typical coastal habitats of lagoons and seagrass meadows. Moreover, Rongcheng has rich biodiversity and fishery resources including swans, prawns, eagle claw shrimp, yellow croaker, flounder, scallops, kelp and wakame.

The economic development of Rongcheng is mainly driven by the marine or "blue" economy, and the value of the marine fishery and aquaculture dominates the whole industrial food-system. After decades of aquaculture and urbanization, Rongcheng has developed as a National Marine Ranch Demonstration Area where the dominant economic sectors are aquaculture and fisheries. Rongcheng includes a breeding area of 388 km^2, 5 national marine ranches and 11 national, leisure-fishery demonstration areas. The output of aquatic products (1.25 million metric tons) and the total fishery income (15.0 billion USD in 2020) have been ranked first, at the national level, for 39 years. This accounts for a substantial contribution to the total annual aquaculture production in China, for example kelp (31%), sea cucumber (14%) and abalone (5%).[3] Rongcheng has 2, first-class open ports and 10 first-class open harbors, with the cargo throughput capacity over 25 million metric tons. Rongcheng possesses 317 professional, ocean-going fishing vessels, accounting for 70% of the Shandong Province pelagic fishing fleet. Rongcheng has more than 260 marine food companies, with an annual income from sales reaching 20 billion USD, according to the official website of the local government. Rongcheng is the largest production base for frozen prepared food, kelp, seafood and canned food in China. The tourism industry in Rongcheng is also very developed, with about 12 million domestic and foreign tourists annually. Other important economic sectors include agriculture, shipping and urbanization.

A multitude of resulting pressures come mainly from human activities including intensive aquaculture, overfishing, industry pollutant discharge, agriculture runoff, coastal land reclamation and port construction (Ni et al., 2017; Shao et al., 2019). These have led to changes in the state of the environment and ecology, such as pollution by heavy metals and persistent organic pollutants (POPs), marine debris and microplastics, eutrophication, seagrass meadow degradation, and shoreline recession (Wang F. et al., 2017; Sui et al., 2020). This environmental degradation has resulted in a reduction in the delivery of valuable ecosystem services, such as the provision of quality seafood, cultural heritage, which also impacts on human welfare, human health and the sustainable development of the local economy. In addition, Rongcheng is also facing exogenic pressures from the extreme climate events, such as intensified coastal storms, storm surges, beach erosion, droughts and sea ice. These have resulted into the erosion of the natural shoreline, the decline of coastal

[2]http://www.rongcheng.gov.cn/col/col61812/index.html

[3]http://tjj.weihai.gov.cn/col/col12005/index.html

TABLE 1 | Stakeholders related to the Rongcheng City coastal development.

Sector	Governance	Private company	Civil society/community and research institutions
Aquaculture/fishery	North China Sea Branch of State Oceanic Administration China Fisheries Law Enforcement (in Yellow Sea and Bohai Sea) Rongcheng Municipal Ocean and Fishery Affairs Bureau Shandong Ocean Bureau Shandong Hydrobios Resources Conservation and Management Center Rongcheng Station for Popularizing Fishery Technique	Xunshan Group Co., Ltd. Shandong Homey Aquatic Development Co., Ltd. Chudao Fishery Co., Ltd. of Rongcheng Yantai Sanhang Radar Service Technology Research Institute Co., Ltd.	Rongcheng fishery Association Yellow Sea Fisheries Research Institute (YSFRI), Chinese Academy of Fishery Sciences Ocean University of China (OUC) Yantai Institute of Coastal Zone Research, Chinese Academy of Sciences (YICCAS) Marine Biology Institute of Shandong Province Ludong University Institute of Oceanology, Chinese Academy of Sciences (IOCAS)
Agriculture	Rongcheng Municipal Agriculture Bureau Rongcheng Food and drug Administration	-	-
Maritime Navigation and Transport	Weihai Maritime Safety Administration Weihai Port and Shipping Administration Bureau Rongcheng Transport Administration Bureau (Port and Shipping Administration Bureau)	Xunshan Group Co., Ltd. (Lijiang Harbor) Chudao Shipyard Yantai Sanhang Radar Service Technology Research Institute Co., Ltd.	-
Industry (mining, Petrochemical, salt . . .)	Weihai Municipal Bureau of Land and Resources Weihai Bureau of Salt Industry	-	Ludong University
Leisure (Tourism)	Rongcheng Station for Popularizing Fishery Technique	Weihai China Travel Service Co., Ltd. The Base for Recreational Fishing The Museum of Traditional Culture and Seagrass House	Shandong Tourism Trade Association
Sewage treatment	Weihai Municipal Environmental Protection Bureau Weihai Municipal Ocean and Fishery Affairs Bureau	Rongcheng Sewage Treatment Plants	Ocean University of China (OUC) Yantai Institute of Coastal Zone Research, Chinese Academy of Sciences (YICCAS)
Coastal engineering	Weihai Municipal Bureau of Land and Resources Shandong Provincial Cultural Relics Bureau The National Cultural Relics Bureau	Yantai Sanhang Radar Service Technology Research Institute Co., Ltd.	Yellow Sea Fisheries Research Institute (YSFRI), Chinese Academy of Fishery Sciences Ocean University of China (OUC) Yantai Institute of Coastal Zone Research, Chinese Academy of Sciences (YICCAS) Ludong University

habitat and an increased vulnerability of the population to natural hazards.

Data Sources

The information and data used were obtained from the following resources:

(1) Bibliographical survey: The sources include published reviews and research articles, books and book chapters, master/doctoral degree theses, government reports.
(2) Field and monitoring data: Field investigation and sampling to determine state variables, such as rates of erosion, condition of seagrass meadows;
(3) Multi-temporal remote sensing images: Mapping and assessing areas devoted to aquaculture and the extent of seagrass meadows;
(4) Outcomes of participatory processes: These included minutes of face-to-face interviews, meetings with stakeholders, oral presentation slides from the local representatives during the stakeholders' meeting, project deliverables. The participatory process is summarized in **Tables 1** and **2** and in *Participatory Process*.

Participatory Process

The transdisciplinary approach had not been used previously for studies in coastal sustainability in China. The Yantai Institute of Coastal Zone Research, Chinese Academy of Sciences (YIC-CAS), initiated the work was supported by the CAS President's International Fellowship Initiative (PIFI), to involve international experts to help with the initiation of the process. A variety of stakeholder engagement tools was used in the work including questionnaires, meetings and presentations.

Step 1 Identification of stakeholders: The researchers from YIC-CAS carried out a mapping exercise that identified 40 potential stakeholders. These were categorized by sectors (e.g., fisheries/aquaculture/shipping) and then allocated to the following four groups: government, private companies, civil society/community and research institutions (**Table 1**), to ensure balance and cross-sectoral representation.

TABLE 2 | Stakeholder participation and the level of engagement.

Stakeholder identification		Issue 1 Poorly regulated aquaculture	Issue 2 Loss of shoreline	Issue 3 Decline seagrass bed and seagrass house	Online questionaires	Responses (measures)	Meetings and on-going forum
Set One	Shandong Ocean Bureau	yes	yes	yes	yes	yes	yes
	Shandong Hydrobios Resources Conservation and Management Center	yes	yes	yes	yes	yes	yes
	Chudao Fishery Co., Ltd. of Rongcheng	yes	yes	yes	yes	yes	yes
	Yantai Institute of Coastal Zone Research, Chinese Academy of Sciences	yes	yes	yes	no	yes	yes
	Rongcheng Station for Popularizing Fishery Technique	yes	yes	yes	yes	yes	yes
	Rongcheng Fishery Association	yes	no	yes	yes	no	yes
	Chudao Shipyard	yes	yes	yes	yes	no	no
Set Two	The People's Government of Rongcheng Municipality	yes	yes	yes	no	yes	yes
	Shandong Homey Aquatic Development Co., Ltd.	yes	no	no	no	yes	no
	Rongcheng Municipal Ocean and Fishery Affairs Bureau	yes	no	no	no	yes	yes
	Weihai Municipal Ocean and Fishery Affairs Bureau	yes	no	no	no	yes	yes
	Ludong University	no	yes	no	no	yes	yes
	Yantai Sanhang Radar Service Technology Research Institute Co., Ltd.	no	yes	no	no	yes	yes
	Institute of Oceanology, Chinese Academy of Sciences (IOCAS)	no	no	yes	no	yes	yes
	Mashan Group Co., Ltd.	no	no	yes	no	yes	no
	Yellow Sea Fisheries Research Institute (YSFRI) Chinese Academy of Fishery Sciences	no	no	yes	no	yes	yes
	Ocean University of China (OUC)	no	no	yes	no	yes	yes
	China Foundation For Cultural Heritage Conservation	no	no	yes	no	yes	no
	Shandong Provincial Cultural Relics Bureau	no	no	yes	no	yes	no

Step 2 Invitation to participate: All the potential stakeholders were then contacted and invited to participate by YICCAS and the local government. Contacts were made through various means, including meetings, emails, and phone calls. The initial contacts were followed up to confirm if they were interested in participating in the study and to encourage them to do so.
Step 3 Issues questionnaire: The stakeholders who engaged then participated in a questionnaire survey to identify their perception of the main issues for coastal sustainability under climate change, as explained in detail in *Issue Identification*.
Step 4 Introduction to transdisciplinary adaptive management: The stakeholders were invited to attend presentations about the purpose of adaptive management frameworks and transdisciplinary co-design. The subsequent process and their involvement were explained to encourage continued participation.
Step 5 Issue identification: The stakeholders who were brought together in a meeting to interact and deliberate reached a consensus on the main issues related to sustainable development in Rongcheng City based on the results of the questionnaire (step 3).
Step 6 Engagement of additional stakeholders: Further stakeholders were invited and encouraged to participate as interested parties, based on the identified issues. The adaptive management framework, the subsequent process and their involvement were explained.
Step 7 Parallel stakeholder sessions: The stakeholder process continued in parallel between stakeholders grouped according to the different issues. The stakeholders used the adaptive framework to analyze each of the main issues and arrive at management options.
Step 8 Joint stakeholder meeting: A series of meetings was held to analyze the possible responses and measures identified for each issue in Step 7.
Step 9 Management plan: The stakeholders co-designed an adaptive management plan.

Adaptive Management Frameworks

Binder et al. (2013) compared the advantages of 10 different frameworks finding that some frameworks are more suitable in a coastal, social-ecological analysis. For example, the Systems Approach Framework (SAF) is a methodological framework for the transition to sustainable development in coastal zones (Newton, 2012). The SAF was developed for providing multidisciplinary and trans-disciplinary advice to environmental managers and policy-makers concerning environmental problems in the coastal zone (Baltranait et al.,

2020). The key parts of the SAF approach - System Definition, Stakeholder Mapping, and Issue Identification are fundamental steps of the adaptive management framework.

The Drivers-Pressures-States-Impacts-Responses (DPSIR) is another framework initially developed by the Organization of Economic Cooperation and Development (OECD, 1993) and then adopted by the European Environment Agency (EEA, 1995). It has been widely used to analyze issues of sustainable development and in Integrated Environmental Assessment, especially in coastal zones (Gari et al., 2015) and the recent UN World Ocean Assessment.[4] This framework has evolved (Elliott et al., 2017) to eliminate confusion in terminology (Patricio et al., 2016).

Adaptive management frameworks also need to be adapted to the local situation. Different frameworks offer different approaches and some omit aspects that others include. Contributions from the frameworks were combined and used in the Rongcheng case study. The SAF approach was applied in this study to ensure full participation of appropriate stakeholders from government, scientists and communities. Based on the SAF, three main issues impeding the sustainable development of Rongcheng City under the co-influences of climate change and human activities were identified. Once the issues, corresponding system and stakeholders were defined, an adapted DPSIR framework (Elliott et al., 2017) was used to analyse each issue and identify suitable measures as a response. Combining features of the different frameworks, adapting them to the local issues and situation has been successful in several different settings and for different issues (Semeoshenkova et al., 2017; Berninsone et al., 2018; Tseng et al., 2018; El Mahrad et al., 2020; Abalansa et al., 2020).

RESULTS

System Definition and Stakeholder Mapping

The social-ecological system defined in this study is the land area of Rongcheng City and its adjacent sea area. Rongcheng City is the most prominent county-level city of traditional aquaculture and fisheries in China, which has a long history of integrated multi-trophic aquaculture. With the development of marine fishery and urbanization, coupled with extreme weather, such as storm surges, the problems and contradictions of the aquaculture environment, offshore ecosystem and folk culture are most prominent in this social-ecological system.

For the stakeholder mapping, according to their chronological order of participation in the research, the stakeholder candidates were classified into two sets, Set One and Set Two (**Table 2**). Most of the stakeholders in Set One have been involved in the entire work from 2014 to 2019. The second set of stakeholders were further chosen by the government to engage and implement responses and measures, according the management plans of different issues already identified. The result of the stakeholder mapping is summarised in **Table 2**.

Chudao Fishery Co., Ltd. of Rongcheng is a typical representative of fishery companies and one of the main stakeholders from the commercial sector. It is a comprehensive company integrating seafood breeding, nursery, freezing, processing, as well as tourism and sightseeing. The company has cooperated with the Chinese Academy of Sciences, the Chinese Academy of Fishery Sciences and Universities. They are established as a science and education experimental base for Ecological Farming and Marine Science. The company is organized on the basis of a local administrative village and also represents the local residents. With the dual identity of local administrator and fishery company, as well as one of the initiators of the research, the company played an important role in the transdisciplinary, co-designed process throughout this study.

Shandong Ocean Bureau (former Shandong Provincial Department of Ocean and Fisheries) is a typical stakeholder from provincial authority. It is responsible for formulating plans for the development of marine industry, industrial layout and efficient use of marine resources, drawing up and organizing the implementation of plans for marine technology development, the allocation and use of marine areas, island protection and utilization management. It provided research funding and promoted the implementation of several response measures of this study.

The Peoples' Government of Rongcheng Municipality is the local government, responsible for organizing and managing various administrative affairs in the administrative area of Rongcheng. It adopts the consulting suggestions from scientists on the sustainable development of Rongcheng, and formulates and promulgates the corresponding planning and management regulations. This science-policy link guaranteed the implementation of the adaptive management plan.

Another stakeholder representing local authority is the Rongcheng Station for Popularizing Fishery Technique, which is a unit directly under the Rongcheng Ocean and Fishery Bureau. It is responsible for promoting fishery technology and development. In this study, it participated in scientific research, especially in the fisheries planning and habitat restoration.

Several important stakeholders representing the scientific community come from Chinese Academy of Sciences, the Ministry of Agriculture and Rural Affairs, universities and provincial research institutions. In addition, Rongcheng Fishery Association and China Foundation for Cultural Heritage Conservation were identified as the NGOs in this study, who provided important advice and response measures in the transdisciplinary participatory process.

Issue Identification

A list of five locally contextualized issues, including (A) Aquaculture pressures; (B) Loss of seagrass meadows; (C) Shoreline erosion; (D) Reduction of fish stock; (E) Lack of job opportunities were identified through the analysis of literature. Based on the above, a questionnaire on the main issues of Rongcheng's sustainable development was designed. All the stakeholders were engaged to rank the importance of the main

[4]https://www.worldoceanobservatory.org/content/un-world-ocean-assessment

TABLE 3 | Ranking and integrating of issues.

No.	Issue	Means of identification	Ranking	Inter-related issues	
A	Aquaculture pressures	Literature survey	1	1	
B	Loss of seagrass meadows		4		3
C	Shoreline erosion		3	2	
D	Reduction of fish stock		2	1	
E	Lack of job opportunities		5		3
F	Poor governance and management of aquaculture licenses and activities	Open answers from Questionnaire		1	
G	Degradation of cultural heritage and especially the traditional of the seagrass thatched houses				3
H	Unsustainable fishery practices			1	

Results of Stakeholder analysis of issues

Rank	Issue	
1	Poorly regulated aquaculture	A + D + F + H
2	Loss of shoreline	C
3	The decline of seagrass and decline of cultural heritage	B + E + G

issues listed in this questionnaire, add further issues and give their feedback through emails, telephone and on-site meetings.

The statistical analysis of the responses to the questionnaires, together with face-to-face interviews and meetings, ranked the issues in order of importance, and the result was A-D-C-B-E. Three other issues were raised by the stakeholders besides the five initially identified. These were (F) poor governance and management of aquaculture licenses and activities; (G) degradation of cultural heritage and especially the traditional of the seagrass thatched houses; (H) unsustainable fishery practices. In view of the connection between the eight issues and their prominence, these issues were integrated, summarized and analyzed by the first sets of stakeholders. A, D, F and H were combined as the most prominent aquaculture issue, C as the most urgent shoreline issue, then B and G combined as the most concerning issue about seagrass and seagrass houses. E was considered as a negative effect resulting from some of these issues. Finally, three issues urgently related to the sustainable development of Rongcheng were focused on. They were 1) poorly regulated aquaculture; 2) loss of shoreline; and 3) the decline of seagrass and decline of cultural heritage (**Table 3**).

DPSIR Analysis for Sustainability of Roncheng City

In this section, three main issues and their DPSIR analysis are explained in detail and are summarized in **Table 4**. Some issues share the same drivers and pressures, and the others require similar responses. Moreover, the response to one issue can produce a pressure on another issue or even introduce a new issue (Berninsone et al., 2018). The response discussed below indicates the possible measures based on the analysis of DPSI of each issue.

DPSIR Analysis of Unregulated Aquaculture

Rongcheng was a traditional seaweed farming village. Due to its unique geographical location, the coastal area of Rongcheng is one of the best places to farm kelp (*Saccharina japonica*). More than 80% of China's total kelp production came from Rongcheng in 2016, earning it the title of "*home of kelp*". At present, there are 260 kelp nursery and breeding enterprises, with a breeding area of 40,000 hectare, an annual output of more than 500,000 metric tons of kelp, and an output value of more than 300 million USD (Rongcheng Fishery Technology Extension Station, 2017). The other main cultured species are the oyster *Crassostrea gigas*, the scallops *Chlamys farreri* and *Patinopecten yessoensis*, and sea cucumber *Apostichopus japonicus*. The production of oyster and scallop was 66,200 and 13,500 t yr^{-1}, respectively, in 2016 (Rongcheng Fishery Technology Extension Station, 2017). All the species are grown in suspended culture, by placing the kelp seedlings or oyster seed on a rope or scallop in suspended cages (Gao et al., 2020). In 2017, the area of sea cucumber cultivation exceeded 1,000 ha and the production accounted for 16% of the national total production.[5]

The ***pressures*** from the development of aquaculture and fisheries are the disordered structure and layout of aquaculture, overstocking and the increasing wastewater discharge. As a result, the ***state change*** of the ecosystem is loss of biodiversity and bio-resources, and environmental degradation. The dissolved nitrogen concentrations increased significantly and the average nitrogen/phosphorus ratio increased after 2010 approximately three to four times more than the 2006 value due to rapid expansion of mariculture (Li et al., 2017). Consequently, the proportion of dinoflagellates in phytoplankton increased from 4 to 9% between 2011 and 2014 and the pH also presented a potential declining trend since 2011 (Li et al., 2017). Both kelp and bivalve farming induced significant spatiotemporal variations in the carbonate system within the Sanggou bay (Li et al., 2021). Moreover, the abundance of microplastics in the surface sediments was at high level with

[5]http://www.shuichan.cc/news_view-343617.html

TABLE 4 | Results of DPSIR analysis: Issues-Drivers-Pressures-States-Impacts-Responses.

Issues	Drivers	Pressure	States	Impacts	Responses
Unregulated aquaculture	• Fisheries activities	• Aquaculture layout • Overfishing	• Increased pollution by antibiotics, toxic metals, microplastics and others • Changes in nutrient conditions and decline in the quality of aquaculture and seafood	• Health risk to inhabitants • Loss of income and jobs	• Scientific research on pollutants • Reasonable breeding layout • Breeding standards and norms • Employment Guidance • Healthy aquaculture pattern
Loss of shoreline	• Urbanization • Fisheries Activities • Nature processes (storm surge, etc)	• Pollutant discharge • Shoreline change	• Shoreline change • Shoreline erosion	• Production reduction in aquaculture • Loss of income	• Scientific research • Conservation measures • Restoration projects
Decline of seagrass and cultural heritage	• Urbanization • Fisheries Activities • Lifestyle changes	• Space encroachment • Pollutant discharge • Subjective willingness to protect folk culture	• Loss of seagrass meadows • Damaged and abandoned traditional, thatched houses	• Loss of Ecosystem services • Loss of income, jobs • Loss of culture value	• Scientific research • Conservation measures • Restoration projects • Planning, conservation and marketing of cultural tourism

1,674 ± 526 items/kg dry weight, of which approximately 57.7% of the microplastics originated from the plastic mariculture facilities (Sui et al., 2020).

The direct ***impact*** on human welfare is the loss of income due to unregulated behavior by individual aquaculture farmers and the subsequent decline of market price. Another ***impact*** is the increasing risk to food safety due to environmental pollution caused by the wastewater from aquaculture. The latter not only poses a threat to the human health, but also results in a decrease in the income for farmers because of cheaper price from decline in quality. Therefore, it is necessary for all the stakeholders to co-design an adaptive management plan.

The first urgent ***response*** to this issue is aquacultural planning, which can strictly delimit non-aquaculture areas such as ecological protection areas and aquaculture areas. It is beneficial to protect coastal habitats and facilitate the subsequent management and research of aquaculture. Secondly, scientific monitoring and impact assessment of the aquacultural environment are crucial to the better understanding of the environmental and ecological quality of Rongcheng. Thus, a sound management regulation system is vital to regulate the random behaviors by individual aquaculture farmers. Finally, the stakeholders will jointly probe healthy aquaculture patterns and technologies, such as "Integrated Multi-Trophic Aquaculture (IMTA)"and "Modern Marine Ranching," explore its characteristic industry chain, such as "Recreational fishery" and "Aquatic products processing industry," and ultimately realize the sustainable development of aquaculture in Rongcheng. The formulation and implementing of the transdisciplinary, co-designed and adaptive management plan will be explained in *Transdisciplinary, Co-Designed and Adaptive Management Plan*.

DPSIR Analysis of Loss of Shoreline

Rongcheng city has a long, sandy, coastline with a total length of 62.6 km and mean beach width of 37.2 m (Li et al., 2013). Natural hazards such as storm surge, large storm waves and sea level rise are important natural drivers of loss of shoreline. The main ***activities*** along the shoreline are thousands of aquaculture ponds of different sizes, as well as the beach tourism that attracts 11.5 million every year, supporting the City's GDP by 8.6 billion RMB (Yearbook Compilation Committee of Rongcheng, 2017).

The habitats are facing significant pressures due to shoreline modification. Since 1988, artificial or modified shoreline by dams or aquaculture activities now account for 39.44% of the total shoreline in Weihai City, including Lidao Bay and Shidao Bay of Rongcheng City (Sun et al., 2019). The ***change of state*** of the coastline is its dramatic degradation by both natural hazards and human activities resulting in sediment deficit. Coastal erosion, caused by natural hazards and human activities, such as sand excavation and coastal engineering, significantly threatens the sandy beaches in Dongchudao Village of Rongcheng City (e.g., **Figure 2A**). Beaches in Jingzi Bay and Yulong Bay have disappeared completely, while the sand dunes of Daxizhuang have retreated tens of meters in the last decades, resulting from large area of pine forests collapsed into the sea (Li et al., 2013).

This degraded coastline has ***impacts*** on human welfare. Coastline erosion and suspended particles in the water column increase turbidity, affecting primary production (such as kelp) and other seafood resources in offshore breeding pond. This leads to the loss of the income for local fishers with lower catch and lower value of the catches. Moreover, conversion to artificial shorelines decreases beach tourism in Rongcheng, decreasing

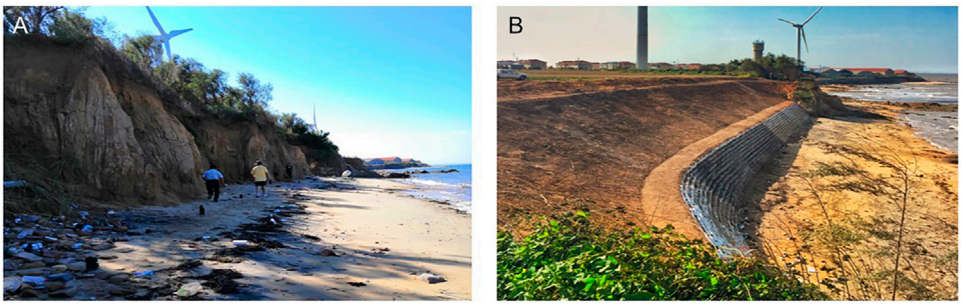

FIGURE 2 | Shoreline recession before **(A)** and after **(B)** ecological restoration was undertaken in Dongchudao village, Rongcheng.

both the number of tourists and the income of the tourism industry.

Thus, the main ***response*** to the loss of shoreline is to clarify the reasons and mechanisms of shoreline loss, and to design and conduct corresponding shoreline restoration projects. The formulation and implementing of the transdisciplinary, co-designed and adaptive management plan will be explained in *Transdisciplinary, Co-Designed and Adaptive Management Plan*.

DPSIR Analysis for Decline of Seagrass and Cultural Heritage

Another kind of well-known habitat in Rongcheng is seagrass meadows, mainly of *Zostera marina* and *Zostera japonica*, covering 553.84 ha mostly in Swan Lagoon, Sanggou Bay, Lidao Bay and Moye Bay of the City (Zheng et al., 2013; Li et al., 2019). However, decades of aquaculture and urbanization activities have encroached on seagrass meadows. The ***pressure*** on seagrass meadows comes from the space encroachment caused by expanding aquaculture and urbanization, and the environmental pollution releasing from the aquaculture farms and onshore areas. From 2000 to 2018, the marine aquaculture area in Rongcheng expanded from 153 to 381 km^2, an increase of 150%, and the annual output of marine fisheries (including marine fishing) increased by 31%; in the context of urbanization, the proportion of agricultural population in Rongcheng City dropped from 70% of 2000 to less than 44% of 2018.[6] These pressures are changing the ***state*** and causing a decline of seagrass and 90% of the seagrass habitats in Rongcheng have been lost in the last 30 years (Zheng et al., 2013; Fu et al., 2021). These blue carbon habitats, with carbon burial rates of 121–976 g C m^{-2} yr^{-1} and sediment accretion rates of 11.6–40 mm, are acting as efficient regional carbon sinks, as well as buffers of the rising sea level (Fu et al., 2021). Following disturbance or conversion of the seagrass meadows, a portion of the organic carbon preserved in the top meter soils becomes exposed to oxic conditions, which discharge approximately 0.72 Tg CO_2 into the atmosphere, resulting in negative effects on climate change mitigation. The seagrass habitats also provide significant additional ecosystem services and benefits such as juvenile fish nurseries and pollution filtering. Moreover, the seagrass harvested in Rongcheng is a culturally important heritage as a traditional thatching material of the distinctive seagrass roof houses that are characteristic of the city.

The decline of seagrass ecosystem services resulted in ***impacts*** on human welfare. The limited supply of roof seagrass material also affects the maintenance of traditional seagrass houses threatening the distinct culture heritage of the city and the tourism linked to it. Seagrass-thatched houses have great value in historical, cultural and architectural aesthetics and research on traditional lifestyles and crafts (Wang, 2011; Li et al., 2020). They are crafted by skilled fishermen on the Jiaodong Peninsula and a model of harmony between natural and artificial. However, the decrease in the supply of seagrass has led to the decline of the traditional seagrass market and the seagrass house construction industry and the loss of seagrass house craftsmen. There has been an increase in market prices of seagrass from a few cents to a few USD per kilogram. The price of seagrass thatched roofs is almost 10 times more expensive than brick-tile, so the villagers cannot afford to build or repair their seagrass houses (Ma et al., 2019). More than 58% of the traditional villages of seagrass houses are currently in a state a poor state and most of the existing seagrass houses have shown varying degrees of damage and even their gradual disappearance. This has led to a decline in the number of seagrass houses (Wang S. G. et al., 2017). In the 2006 census survey, there were 95,000 seagrass houses in Rongcheng, but in 2016, there were less than 10,000 seagrass houses, a loss of 10,000 seagrass houses per year (Jin and Wang, 2016; Li et al., 2020). Of course, the decline of traditional seagrass houses is not only caused by the loss of seagrass habitat, but has also resulted from changing concepts about housing and the processes of coastal urbanization. Nevertheless, the decline of this kind of cultural heritage is an unfortunate consequence.

The decline of seagrass meadows directly leads to the lack of raw materials for seagrass houses. Therefore, the primary response is to implement the restoration of seagrass meadows. Meanwhile, strict management regulations are also needed to prohibit the encroachment from aquaculture and urbanization. Regarding the decline of traditional seagrass houses, responses need to be initiated by the governors to develop and implement conservative remediation plans, to seek remediation funds, and to explore sustainable cultural industry together with

[6]http://tjj.weihai.gov.cn/col/col12005/index.html

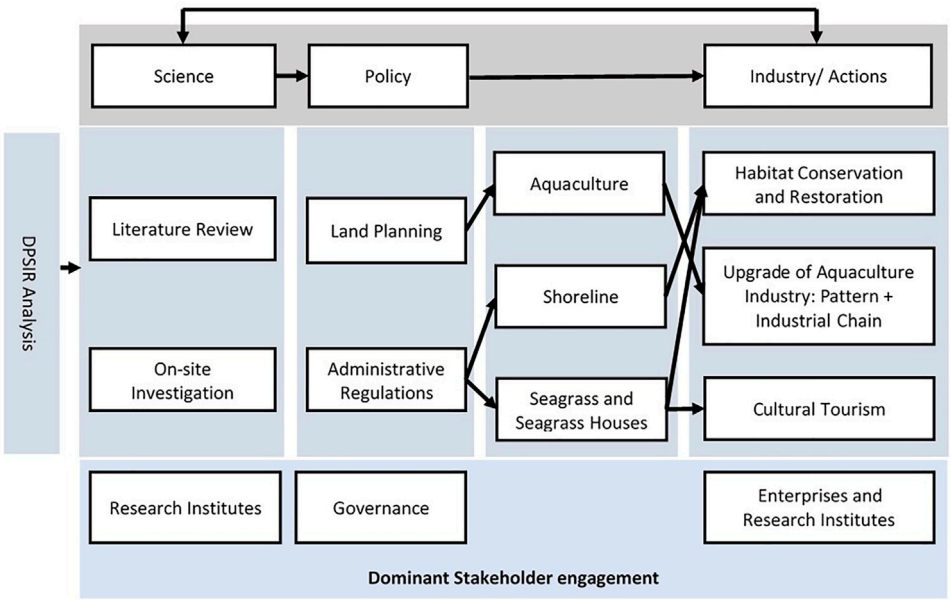

FIGURE 3 | Transdisciplinary, co-designed, adaptive management plan.

representatives from institutes or universities, industries, associations, NGOs and local residents. The formulation and implementing of the transdisciplinary, co-designed and adaptive management plan will be explained in *Transdisciplinary, Co-Designed and Adaptive Management Plan*.

Transdisciplinary, Co-Designed and Adaptive Management Plan

Based on the DPSIR analysis of three main issues, a transdisciplinary, co-designed and adaptive management plan was proposed and submitted to the two levels of government, both Rongcheng City and Dongchudao Village. Some of the suggestions proposed by this study have been adopted and implemented by the government.

Content of Management Plan

The first set of stakeholders discussed the three main issues about the sustainable development in Rongcheng to reach a consensus about potential responses to **Table 4**. They ranked the management options, in terms of urgency, as follows: 1) Reasonable breeding layout and standards; 2) Measures of conservation and restoration for vulnerable habitats; 3) Healthy aquaculture pattern; 4) Cultural conservation and marketing; with 5) Scientific research necessary throughout. They subsequently drafted a co-designed, adaptive management plan (**Figure 3**) based on the analysis.

Three aspects were considered in the plan, Science, Policy and Industry/Action. Research institutions and universities together led the implementation of scientific research with inputs from the community. They carried out literature reviews, field investigation and sampling, to monitor and assess the ecological and environmental state. They advised the policy makers on how to implement specific measures, such as upgrading the aquaculture industry upgrading and shoreline resource restoration. The role of the government and administration is spatial planning, regulation, management and supervising the implementation of the response measures. The spatial planning includes land and coastal zoning, breeding areas and protected areas. Regulations include industry regulations, regulations for the protection of the coastline and seagrass meadows. They also include management and restoration, for example of seagrass houses. Representative enterprises/companies, research institutes/universities and community cooperate and are responsible for actions to implement the measures that are approved by the policy makers.

Implementation Progress

Aquaculture Planning: At present, based on but not limited to this study, the "Tidal Flat Planning for Aquaculture Waters in Weihai City (2018–2030) has been implemented, delimiting the tidal flat space for the aquaculture area (http://www.weihai.gov.cn/art/2020/2/25/art_51907_2277601.html)". The traditional aquaculture is shifting to green and sustainable aquaculture by successively enacted policies on Green Development, reflecting the great importance attached by the government at all levels to the construction of national modern marine ranches and the integrated multi-trophic aquaculture (IMTA) as the main management ***response***. In Sanggou Bay, the ecosystem production was much more than the circulation of matter and flow of energy and the social benefits are higher than the private benefits after the application of IMTA, which is a promising way to minimize the disturbance of aquaculture to protect the ecosystem and improve economic benefits for stakeholders (Yu

et al., 2017; Sun et al., 2020). The aquaculture is going through an evolution from an extensive, traditional aquaculture to the current intensive, 3D farming method. Authorities in Rongcheng have been touting "*China's first 5G fish farm*," equipped with real-time camera technology provided by Huawei helping assist with feed management (Godfrey, 2019). Research institutions such as the Institute of Oceanology, Chinese Academy of Sciences, universities such as the Ocean University of China and aquaculture associations have provided scientific guidance to aquaculture producers and enterprises in areas such as stocking density, choice of which species to raise, and the most economic breeding method to follow (Wang et al., 2020). Aquaculture enterprises such as Shandong Homey Aquatic Development Co. Ltd. have promoted new aquaculture technology and trained local farmers in Rongcheng for sea cucumber breeding. As a result, the company has become one of the 10 biggest aquaculture companies in China, and Rongcheng has become the "National Sea Cucumber Breeding Standardization Demonstration Zone".

Shoreline Restoration: The local and provincial governments have set up a series of stipulations and projects to protect and restore coastal habitats. In 2017, the city issued the local coastal ecological protection regulations, prohibiting coastal land reclamation and sand extraction in the coastal zone (http://www.rongcheng.gov.cn/art/2017/7/31/art_40961_1107178.html). Collaboration between research institutions, local governments and relevant enterprises has been initiated, and some engineering and ecological restoration projects have been conducted to protect the shoreline from further retreating (**Figure 2B**). The height of the revetment in the project was designed based on the maximum wave runup under the extreme climate conditions such as typhoons and storm surges. In 2019, the completed revetment successfully withstood the damage of Typhoon Lekima and prevented the erosion of the shoreline.

Seagrass Meadows and Seagrass Houses Conservation: Research institutions, local governments and relevant enterprises have jointly launched the ecosystem reconstruction project to implement the restoration and conservation measures, such as the seagrass seeds and seedling cultivation, and adult seedling transplantation in Swan Lake and Sanggou Bay of Rongcheng (Http://www.ysfri.ac.cn/info/1756/35894.htm). While restoring the seagrass bed habitat, it also improved the aquaculture ecological environment and developed an ecological farming pattern[7] (Yang, et al., 2016; CAS STPDP, 2018). For the seagrass houses, the local government promoted the "Trial Measures for the Protection of Seagrass Houses in Rongcheng City" as early as 2006 (Ma, 2018) and set up tourist resorts and the village memory museums themed as seagrass houses. The Provincial Cultural Relics Bureau and the National Cultural Relics Bureau have successively funded and implemented two phases of seagrass house restoration projects in the Dongchudao Village. These measures will contribute to the restoration of seagrass habitats and the protection of cultural heritage. Further research and practice of adaptive policies are vitally necessary to maintain the habitats and ecosystem services of seagrass meadows.

[7]The ecological farming pattern is a new model to achieve the goal of protection and sustainable utilization. In the text here it refers to the coastal ecological farms and ranches, which are designed and constructed based on ecological principles and modern engineering technologies (Yang, 2017).

DISCUSSION

Stakeholder Engagement

In this study, transdisciplinary, stakeholder engagement ensured effective communications between administration, enterprise and scientists. The first set of stakeholders were invited or recruited by the initiator of this project, YIC-CAS, together with the Chudao Fishery Co., Ltd. of Rongcheng, and subsequently enlarged to include other relevant enterprises, scientific research institutes, local governments and industrial administrators. These stakeholders participated in the co-design of the adaptive management plan. The categories of stakeholders in this study were devised prior according to the typology of inputters, extractor, beneficiaries, affectees, influencers, and regulators (Newton and Elliott, 2016). Nevertheless, in retrospect, all these types are included. However, there is always a room for improvement, for the better engagement in transdisciplinary, participatory processes. For example, more face-to-face meetings and online forums should be consciously organized, and further stakeholders should be identified to ensure a balanced, equitable outcome.

As a result of the active stakeholder engagement, many successful measures or actions have been implemented as an outcome of this study. These include the restoration of the shoreline, the conservation of seagrass meadows and seagrass houses. This may be ascribed to the nested governance at all levels in China, from local to National and the strategic consulting role of scientists. This helps to advise decisions makers and informs industry. There is a deep trust of science that fosters strong links and cooperation among science, policy-makers and industry.

DPSIR Analysis for the Three Issues

The three issues were analyzed separately using the DPSIR framework (**Table 4**). However, they are not separate, as there are multiple interactions that became apparent in the issue definition process. The main ***driver*** of one issue may exacerbate the emergence of other issues, which in turn may produce the same ***pressure*** and ***impact***. In this study, the development of aquaculture as the pillar industry of Rongcheng City is the dominant driving force for unregulated aquaculture. At the same time, the natural shoreline could be destroyed by the development of aquaculture ponds, and coastal seagrass habitats and traditional village are occupied, resulting in the other two issues. Furthermore, these issues share the same pressure and impact, such as waste water discharge and loss of income.

Some responses are appropriate for several issues, yet sometimes the response to one issue may have pressure or impact on another issue. Usually, scientific research is required for all issues. Strict aquaculture planning is also positive for aquaculture health and the

protection of natural shoreline and seagrass meadows. However, shoreline or seagrass restoration projects will affect the aquaculture environment and fishery production.

Given the complexity above, the similarities and differences of DPSIR for the three issues were analyzed in detail by all the stakeholders involved in this study, opinions and suggestions from each group of the stakeholders were fully considered, and the priority of potential response (measures) were discussed together. These were vital to the formulation of the co-designed adaptive management plan.

The Adaptive Management Plan

As a model and epitome of coastal cities in China, Rongcheng city is being significantly affected by global climate change and human activities. An adaptive management plan is urgent to reduce the vulnerability and to support the sustainable development of Rongcheng city.

The transdisciplinary and adaptive management plan based on the integrative responses obtained from the DPSIR analysis has been co-designed by the scientists, representatives from the industrial association, and decision makers from the local government. The proposed responses are supposed to address the issues arising from human, natural and cultural factors on the whole. The delineation of aquaculture and protection zones could not only protect many habitats such as natural shorelines and seagrass meadows, but also regulate aquaculture behavior. The upgrading of the aquaculture industry and the development of cultural tourism could improve the breeding environment, increase the income of residents, as well as protect folk culture. The plan aims to address the local issues concerning sustainable development, providing an appropriate approach for the management of social-ecological systems of Rongcheng. The plan resulted from a two-phase learning process: 1) local managers and other stakeholders were engaged; 2) the practical actions were implemented, the management effectiveness were monitored, and the feedback knowledge were achieved. The plan framework is trans-disciplinary and co-designed. In an academic sense, it integrates the professional guidance of scientists from multiple disciplines such as biology, physics, and geology. Above all, it is transdisciplinary, with actors from research, government, local communities and industry entities. All the results of the analysis are not directly translatable into the plan but do make a contribution that is used by the local regulators in their plans and regulations, for example, Tidal Flat Planning for Aquaculture Waters in Weihai City (2018–2030), Coastal Zone Ecological Protection Regulations in Rongcheng City.

As the main management response, the construction of modern marine ranches is one of the most important measures for the upgrading of aquaculture and fishery industries in Rongcheng City. The adaptive management plan should have an effect through the "full chain design" at three different levels: Stakeholder cooperation; capacity building and appropriate governance. It is fundamental that the stakeholders were engaged to overcome the challenges in coastal environmental monitoring, remediation, and seagrass habitat restoration. The first priority is to agree on and co-develop the theoretical and engineering technology frameworks of coastal protection and sustainable utilization. Capacity building is the next priority. Biologists working together with experienced workers from fisheries and aquacultures are urgently needed to co-develop selective breeding, resource conservation and processing of high output, value-added products. Finally, the science-policy-industry nexus should inform policy makers from national, provincial and local government. Together they will provide the knowledge basis to draft and enact policies and regulations that provide ecological environmental protection and remediation. These joint responses and measures will prevent shoreline erosion and coastal degradation, support seafood provision, revitalize traditional cultural heritage and stimulate the tourism economy. The integration of government, industry, scientific community and the public citizens will implement the transdisciplinary, co-designed and adaptive management plan for the sustainable development of Rongcheng city, in the context of climate change and human activities.

CONCLUSION AND FUTURE PROSPECTS

In this study, clear scientific questions were proposed, which were the three main issues regarding the sustainable development of Rongcheng city from the SAF analysis. Moreover, scientific methods and models were used, namely SAF procedure, DPSIR framework, and trans-disciplinary participation models from community, researchers, government and other stakeholders. Above all, detailed findings led to practical actions. The adaptive management plan was developed and some of the recommendations were adopted and enacted by the local government.

The frameworks of SAF and DPSIR complement each other and if used together can provide a better understanding of the social-ecological systems especially in coastal zone. This case study is a significant experiment to analyze the typical social-ecological systems in China, including stakeholder mapping (two groups), stakeholder participation, issues identification, DSPIR analysis, the formulating of the management plan, and the implementation of some responses (measures). Prior to the study, knowledge was fragmented by economic sector, sub-regions of Rongcheng, administrative departments and scientific expertise (environmental/social). The transdisciplinary approach resulted in more integrated knowledge of the issues and their interrelations. This knowledge synthesis contributed to a plan to solve these problems. The United Nations is currently initiating "The Decade of Ocean Science for Sustainable Development (2021–2030)," which aims at providing a common framework to ensure that ocean science can fully support marine nations to sustainably manage their Oceans. Stakeholders engaged in the study focused on the United Nations Sustainable Development Goals (SDG), especially in SDG 8.9, SDG 12.8, SDG13 and SDG14, for sustainable economic growth, full employment opportunities, and conserve and sustainably use of the coastal resources. In this context, the "Our Coastal Futures" strategy of Future Earth Coasts (FEC) promotes action towards the sustainable development of coasts

and is initiating a "Global Coastal Assessment" project. Chinese coastal cities are vulnerable in the context of climate change and intensified high-intensity human activities. The case study of Rongcheng is an ideal demonstration study site and a comprehensive paradigm for the global coastal assessment, which may contribute to the achievement of the 2030 UN Sustainable Development Goals at a local level. If successful, it can be scaled up to the provincial level (Shandong) and national level (PR China).

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

CT, HM, Z-JY, AN, and YoL designed the case study and analyzed the data. CT, HM, YuL, CF, and YoL wrote the manuscript. Z-JY, AN, and YoL provided invaluable scientific comments and language editing. All authors read and approved the final version of the manuscript.

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The handling editor declared a shared membership of a scientific network with several of the authors CT, AN, and YL at time of review. The reviewer SP declared a past co-authorship with one of the authors AN to the handling Editor.

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