Chapter 14
Urban River Resilience

Jaime Joaquim de Silva Pereira Cabral, Marcos Antonio Barbosa da Silva Junior, Yuri Tomaz Neves, Arivânia Bandeira Rodrigues, and José Adson Andrade de Carvalho Filho

Abstract Urban river resilience involves engineering characteristics including also social and ecological issues. Resilience can be conceptualized as the ability to recover after an impact, returning to conditions prior to the impact or adapting to new conditions. A better understanding of river complexity is necessary for analyzing resilience. The three aspects of urban river resilience can be understood as engineering resilience focuses on maintaining the stability and final efficiency of a system, ecological resilience of a river is characteristic of complex and dynamic living systems, and a socio-ecological resilience requires a transdisciplinary planning including adaptive capacity. Resilience of urban rivers and streams requires a multidisciplinary approach involving architecture, landscape design, hydrology, hydraulics, water chemistry, sociology, legislation, economics, navigation, tourism, fishing, and water sports. Some case studies of Recife City (Brazil) are presented: Capibaribe Park, Parnamirim stream, fisherwomen at Tejipió estuary, Beberibe River. Actions to improve the resilience of urban rivers help to preserve environmental conditions, improve social conditions, and can bring positive aspects to some economic activities such as fishing and tourism. The resilience of urban rivers contributes to improving the resilience of cities.

Keywords Capibaribe River · Ecological resilience · Engineering resilience · Socio-ecological resilience · Parnamirim stream

---

J. J. de Silva Pereira Cabral (✉)
Polytechnic School, University of Pernambuco, Recife, Brazil

Civil Engineering Postgraduation Program, Federal University of Pernambuco, Recife, Brazil
e-mail: jaime.cabral@ufpe.br; jaime.cabral@poli.br

M. A. B. da Silva Junior · Y. T. Neves · A. B. Rodrigues · J. A. A. Carvalho Filho
Federal University of Pernambuco, Recife, Brazil

S. Eslamian, F. Eslamian (eds.), *Disaster Risk Reduction for Resilience*,
https://doi.org/10.1007/978-3-031-08325-9_14

1 Introduction

Resilience can be conceptualized as the ability to recover after an impact, returning to conditions prior to the impact or adapting to new conditions. The concept of resilience was initially applied to the physical properties of materials, and in recent decades it has been expanding, being applied today to psychology, social sciences, health sciences, environment, and others. Watercourses in cities have been highly impacted over the last few decades, leading to the need to better study the resilience of urban rivers and streams.

The concept of resilience has been further developed, including the reduction of the probabilities of failures, the reduction of the consequences of failures, the improvement of recovery conditions, and the reduction of recovery time. In addition to recovering from previous conditions, resilience also involves renewal, reorganization, and adaptation to new conditions.

Other definitions of resilience have been presented keeping the focus but showing minor differences: resilience includes the domains technical, organizational, social, and economic (Bruneau et al., 2003); resilience is defined as the capacity of a system to respond to change or disturbance without changing its basic state (Walker & Salt, 2006); resilience is a complex, multidimensional challenge for urban sustainability (Ahern, 2010).

Urban rivers have multidisciplinary characteristics, and it is necessary that the inherent complexity of relationships within systems be understood. Every river has characteristics of hydraulics, hydrology, hydrochemistry and hydrobiology, erosion, and sediment transport. There are also influences of urban landscape, thermal comfort, the use of banks for various purposes, and economic aspects associated with tourism, water sports, river transport, and fishing. Each of these aspects can be impacted, and resilience can be defined for each of these aspects according to the system's recovery capacity.

In relation to urban watercourses, it is very difficult to guarantee that it will never fail and a new approach seeks to create conditions so that if there is a failure in the flow capacity of the watercourse, it is possible to live with the problem, which has been called "safe to fail." A position "safe to fail" anticipates failures and designs systems strategically so that failure is contained and minimized (Steiner, 2006).

In general, restoring ecological systems in the urban landscape would improve the adaptive capacity of cities. Ahern (2010) explained a design strategy for building urban resilience including features of urban rivers such as multifunctionality, biodiversity, social diversity, multi-scale networks, and adaptive planning. In this context, it is possible to guarantee that the resilience of urban rivers is a first step towards the resilience of cities (Nazif et al. 2021).

2 Engineering Resilience

The term that gives the name to this item has been explored by Holling (1996) in the 1990s, when he subdivided his theory on resilience in the field of ecology (Holling, 1996), started in the early 1970s, in two categories: resilience engineering and ecological resilience.

Holling (1996) stated that engineering resilience focuses on maintaining the stability and final efficiency of a system, which can be measured as the rate at which that system returns to its equilibrium after a disturbance. Gunderson (2000), in his studies, corroborates Holling (1996) when he defined the resilience applied to engineering systems as the return time to a single global balance. In other words, Laboy and Fannon (2016) also stated that engineering resilience is associated with the expected functional stability of technological systems when subjected to disruption.

Urban development on river plains has historically had some advantages such as flat and fertile areas in addition to availability of water for consumption and sanitation development (Miguez et al. 2015a); however, these areas bring with them hydraulic risks and frequent flooding (Miguez et al. 2015a, b).

At the time, the idea of hydraulic engineering was to rectify the riverbed in order that its flows could be taken downstream with greater flow speeds and shorter paths, thus gaining greater land spaces for urbanization and agriculture. But this approach has led to several flooding problems, and in recent years it has been modified to more resilient engineering that can better recover from impacts. As a result, the decisions regarding the construction of infrastructure in cities have been modified to incorporate the management of water resources in the city's rivers and streams (Wheater & Evans, 2009).

For Laboy and Fannon (2016), engineering resilience is usually focused on the technical domain and can be better understood by the R (4R) model – robustness, redundancy, resourcefulness, and rapidity, proposed by Bruneau et al. (2003), which was later adapted by Laboy and Fannon (2016) for the R (6R) model, also including "risk avoidance" and "recovery."

Several researchers have described the components of resilience concepts: robustness – it is given by the strength of the systems and their elements to support or resist stress. Anderies et al. (2004), in turn, use the concept of robustness as one of the possible analyzes of the characteristics of resilience. This concept would be able to discern, objectify, and know the fluctuations of this studied system, that is, how this system can oscillate between the stability and instability of the system in which it is inserted.

Resourcefulness is the excess or excess capacity that allows the continuous function, in case one or more elements or systems fail; these are the goals and end states of a resilient system. Redundancy refers to spare components that can be used if necessary and also refers to the excess capacity that enables continued function should one or more elementsor systems fail (Laboy & Fannon, 2016). Rapidity describes an organization's ability to detect problems and respond to them, while speed identifies the speed at which responses can occur to limit or recover from a shock, both of which are means by which resilience is achieved.

The engineering resilience components included as properties of technical and social resilience are conceptualized by Laboy and Fannon (2016) as risk avoidance must be considered in the initial planning and adaptation stage, in order to encourage the reconfiguration of the built environment according to the realities of current and future environmental forces. Recovery focuses on future adaptation, not only to limit vulnerabilities but also to meet current and future needs.

For Price (2002) and Smit and Wandel (2006), the adaptive capacity, also known as the ability to adapt, demonstrates efforts to explain the sense that resilience does not guide a sense of comfortable or ideal state, but the possibility, the ability to return to a previous situation, even if this previous state is not stable (Cabral & Cândido, 2019; Carpenter et al., 2001; Nyström & Folke, 2001; Price, 2002; Folke, 2006).

The conceptualization of the previous terms is important to assess the engineering resilience in urban rivers from multidisciplinary characteristics such as hydrology, hydraulics, erosion, and sediment transport. Each of these aspects can be impacted, and resilience can be defined for each of these aspects according to the system's recovery capacity.

Recife City is the capital of Pernambuco state in Brazil and has been constructed in an estuarine zone of 3 main rivers (Capibaribe, Beberibe, and Tejipió) with more than 100 streams meandering all over a large plain region (Fig. 14.1). Several dams have been constructed in Capibaribe River in the last decades to increase engineering resilience against floods in Recife (Fig. 14.2).

Another example of engineering resilience applied in Recife is the floodgate system (Fig. 14.3) of the Derby-Tacaruna channel (Fig. 14.1), located in the central area of the city. The channel, which began construction in the mid-1960s, was built on the site of an Old Gamboa, which connected the mangroves of the Beberibe River estuary with the mangroves on the banks of the Capibaribe River. It has a length of 5.30 km, a trapezoidal section of 45.0 m^2 (Emlurb, 2016) with the south exit, connecting with the Capibaribe River, and the north exit, connecting with the Beberibe River.

A few years after the construction of the channel, the road axis built on the banks of the channel began to suffer constant flooding that would be attributed to the various causes that overlap: the subsidence of the roadway, the increase in the waterproofing of the contribution area, the increase intensity of rain, and rising sea levels. With this scenario, the City Hall government, between 1998 and 1999, installed gates at each exit of the Derby-Tacaruna, to prevent water invasion at high tides.

The analysis of engineering resilience in urban rivers requires knowledge of hydrology, hydraulics, structural resistance of channels banks, soil support capacity, and solid waste management. In the case of Recife City, it is complex due to many factors involved. Recife is a coastal city formed by a large plain with low topographical elevations surrounded by a chain of small hills. In addition to the problems of excessive waterproofing that occurs in all large cities, Recife has problems

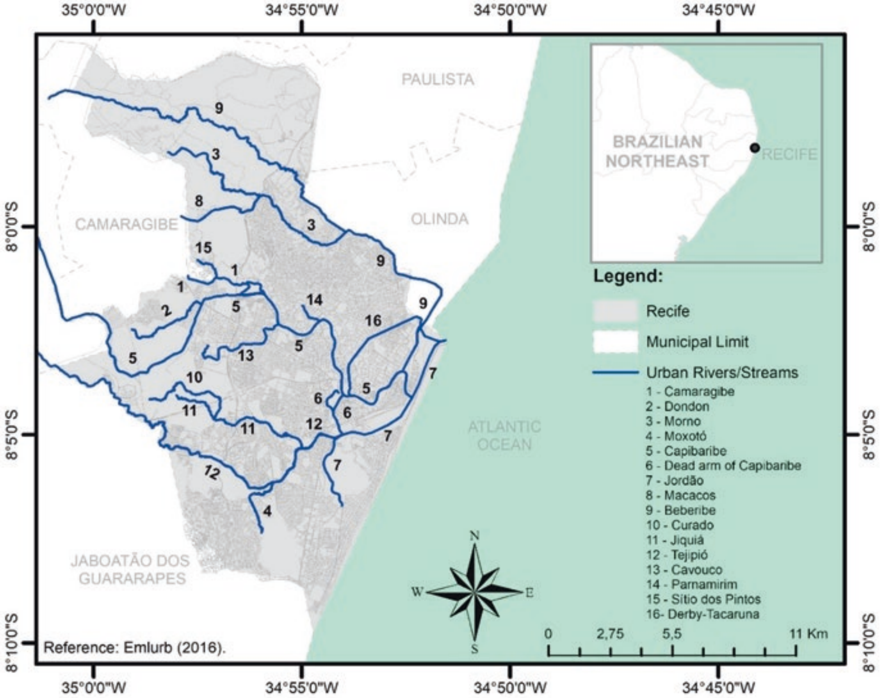

Fig. 14.1 Main urban rivers and some streams that cross the city of Recife, Brazil. (Source: authors)

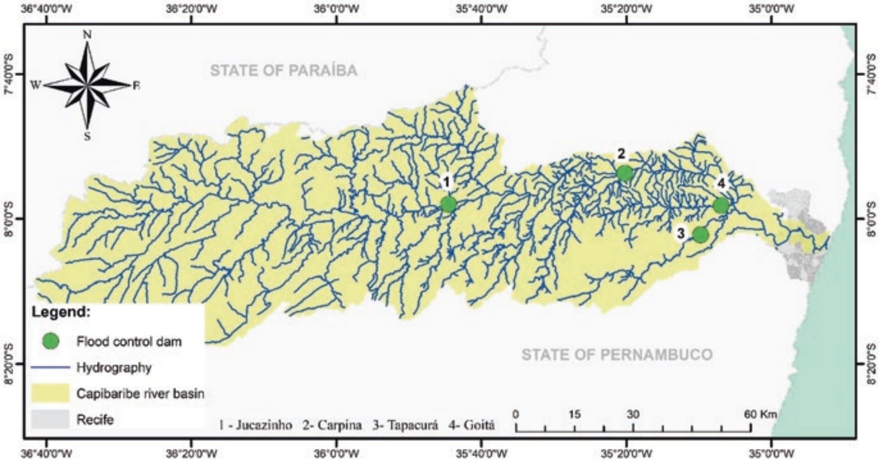

Fig. 14.2 Main dams that have been constructed to improve engineering resilience of Capibaribe River in its urban stretch against floods in Recife (Brazil). (Source: authors)

Fig. 14.3 Gate system (**a**) gate and pumping station at the north end. (**b**) Gate at the south end. (Source: authors)

of great rainfall and the risks of sea level rise, which requires more care to strengthen the resilience of urban river works.

3 Ecological Resilience

The conception of changing the morphology and natural characteristics of the rivers using rectification and channeling brought consequences such as the alarming decrease in the variety of the biota of the river and the riverside areas and floods causing great material damage and sometimes of human lives (Binder et al., 2001).

Ecological resilience of a river is characteristic of complex and dynamic living systems, and the management of urban watercourses has been changed to a multidisciplinary approach including, in addition to hydraulic aspects, fauna and flora aspects, as well as economic and social aspects for a better resilience of urban rivers and streams.

Ecological resilience is the ability of an environment to absorb disturbances and to keep its biota to a minimum so that it can develop a process of renovation, reorganization, and development of its functions (Holling & Gunderson, 2002). This systematic process in which the biological communities of an environment reorganize over a period of time after disturbances, which may have been caused by anthropogenic or natural events, is called ecological succession (Chang & Turner, 2019).

Ecological resilience is associated with activities for restoration, renaturalization, or revitalization. In the case of urban river restoration, the actions to be developed should seek to strengthen the resistance and resilience of the water body (Afonso, 2011). In the present text, the term revitalization will be used despite recognizing that other terms have been used appropriately by several authors.

Another point to think about is that for engineering resilience, quantitative methods of risk management and disaster preparedness generally focus on specific events, but for ecological problems, it is also necessary think about longer-term "stresses" and slower-moving challenges (Rockefeller, 2016).

The revitalization of rivers is the main alternative for protecting the health of ecosystems, preserving water resources, and protecting against floods. This is an idea that has been shared by several countries in the world (Kurth & Schirmer, 2014). The revitalization process goes through planning where a diagnosis of the current situation of the river is made to compare it with an ideal situation. Then the objectives must be outlined considering the ecological conditions of the riparian zones (RZ), which are essential to absorb the natural flood conditions. The fluvial morphological mapping is of fundamental importance for this process, which is a constituent element in the ecology of the aquatic ecosystem, due to its influence on flow, water quality, as well as mobility and renewal of the natural conditions of the bed and bottom aquatic biomass (Binder et al., 2001).

In parallel with the process of degradation of river ecosystems, there are probable losses of countless organisms and losses of their ecological functions in the environment. However, the resilience of these environments is strongly linked to the biota communities that survive this stress (Douglas et al., 2017). The resilience of the species is fundamental for the recovery of the balance of the ecosystem. The biota of the previously disturbed environment tends to regenerate from the stress, due to absorption capacity and survival of some components such as seeds, eggs, and microorganisms (Ayres et al., 2005) that through successive, orderly and gradual processes reach the climax community.

As mentioned by Binder et al. (2001), there are two environments that are fundamental for the revitalization of rivers and streams, the riparian zone (RZ) and the bottom zone of the riverbed, known as the hyporheic zone (HZ). The places that want to make changes in ecological systems are required to manage the resilience of the environment, through changes in development and urbanization policies, preserving the minimum of their functions in order to avoid future environmental tragedies (Adger et al., 2005), such as floods caused by the degradation of riparian zones. As a corrective effect, it is necessary to vacate the buildings in the areas of the banks so that the natural ecological conditions of the river are reestablished.

The RZ is an area located between the river and higher topography lands (Merill & Tonjes, 2014). This area is considered a transition area for several aquatic and terrestrial species helping to regulate ecological functions in both environments. RZ are areas suitable for flooding (Gregory et al., 1991) and have a great plant and biological diversity characteristic of their area (Orozco-López et al., 2018). This area is considered of great importance in water quality, in wildlife habitat, and for human recreation (Ramey & Richardson, 2017). From the hydrological point of view, the RZ maintains the health of the watershed through runoff, which occurs on its surface to water bodies and through infiltration (Orozco-López et al., 2018). The RZ is also a recognized environment for improving water due to the great microbial activity existing in the soil, in addition to its vegetation cover working to protect against erosion and control in the flood regime (Kiley & Schneider, 2005).

At the interface between the surface source and the aquifer, there is an environment known as hyporheic zone (HZ) that functions as a flow regulator between the river and the aquifer, determining the entry and exit of solutes between these environments in addition to serving as a natural filter (Ward et al., 2011). The HZ has definitions depending on the area that is studied, in geology and hydrology. Tonina and Buffington (2009) defined it as a volume of specific sediments that contains amounts of water from the surface and from the underground environment where there is an exchange of water between these two environments depending on the pressure in the riverbed and hydraulic conductivity. From a biological point of view, Dole-Olivier (2011) pointed out that the HZ is a rich environment that undergoes colonization processes for numerous invertebrates. Battin et al. (2016) also mentioned the biofilm existing in the HZ as a complex microbial community that houses a great diversity of algae, fungi, and bacteria that have an important ecological function in the ecosystem, such as the transformation and attenuation of polluting compounds.

Studies have shown the efficiency of HZ in nutrient cycling and as a natural filter capable of attenuating nitrogen, phosphorus, organic carbon (Liu et al., 2017) pharmaceutical products (Schaper et al., 2018), pesticides, and herbicides (Nagy-Kovács et al., 2018). Considered an important habitat for communities of hyporheic organisms, HZ is also a crucial environment in the life of macroinvertebrates such as fish and amphibians, where they lay their eggs that depend, in addition to shelter, on the nutrients that HZ provides for survival and maturation (Soulsby et al., 2009; Williams et al., 2010). Among the organisms that inhabit this area, the meiofauna can be highlighted, which are communities of organisms sensitive to disturbances, which make them great bioindicators of water quality. For example, the excess of nutrients, which is associated with the discharge of wastewater and organic pollution, causes changes to occur in its food chain, completely changing the structure of the community (Pacioglu, 2010).

One of the major concerns in urban rivers is the waterproofing of riverbeds, disconnecting the HZ from surface waters, impairing the hyporheic flow and its ecological functions (Bernhardt & Palmer, 2007). Although numerous studies show the functional and ecological importance of HZ for the aquatic ecosystem, this environment is one of the most threatened by human actions and one of the least protected by legislation worldwide (Mugnai et al., 2015).

The restoration of rivers aims to achieve, as close as possible, the natural state of the river and its ecological functions, admitting small levels of human disturbances. The idea is to recover the resilience of the ecosystem, recover the natural river processes, create a sustainable structure, return the beauty of the river and its banks, and bring back the natural landscape and affective relationship between the river and the population (Del Tánago & Jalón, 2007). In the case of urban river recovery, the actions to be developed should seek to strengthen the resistance and resilience of the water body (Afonso, 2011).

The functional structure and biological complexity of the environment are part of the ecological resilience of a system, both in terms of assimilation of the disturbances received and in terms of ecological succession. Understanding ecological resilience is of great importance to outline objectives and strategies in the river urbanization methodology, mitigating to the maximum the probable risks that these changes can bring.

4 Socio-Ecological or Adaptive Resilience

Despite the resilience in engineering seeks resistance and stability, urban rivers undergo many changes due to urbanization processes and economic activities that their morphological, hydrological, and biological characteristics need to change and adapt to a new situation where resilience is characterized as the search for a new balance. Socio-ecological or adaptive model of resilience recognizes that the stability domain itself is shifting (Laboy & Fannon, 2016).

In the urbanization process throughout the twentieth century, there was a great demand for space for housing and for transportation with the use of individual cars taking the space from the water, so that strangled water courses need to adapt but also requiring new spaces when the river revolts and tries to recover its old spaces, leading urban planners to rethink their plans.

If architects are to be essential social actors organizing the transformation of the built environment, social-ecological resilience is an important conceptual framework for the discourse and a good model for the interplay between the technical, ecological, and social domains (Laboy & Fannon, 2016). Socio-ecological resilience requires a transdisciplinary planning involving architecture, landscape design, hydrology, hydraulics, water chemistry, sociology, legislation, economics, navigation, tourism, fishing, and water sports.

Urban river resilience is imbricated with community resilience. In Atlanta (USA), some developments such as stadium, highways, and parking lots end up causing floods downstream in Turner Field area. A major project has been planned involving urban planners, transportation engineers, community groups, water professionals, and various government entities for implementation of green stormwater infrastructure to improve resilience both of the community and also of urban stream (Diner, 2017).

The objectives of river management based on socio-ecological resilience would be to (a) prevent the system from changing to unwanted configurations in the face of external disturbances and (b) maintain a certain configuration, which allows the system to be reorganized after a massive change (Walker et al., 2007). Disturbances can be seen, within this focus, as opportunities for change and transformation for more desired states (Walker et al., 2007; Hughes et al., 2005).

Urban systems in search of socio-ecological resilience seek to contribute to an interdisciplinary view, since the adaptation of populations requires an understanding of social and environmental relations in an integrated manner. It is a perspective that considers the challenges of simultaneously pursuing economic growth, social inclusion, and environmental responsibility. This seeks to help connect actors involved in spatial planning with a view to spatial sustainability, relating to the city's ecology, sociological architecture, as well as environmental sustainability, fueled by ecology and landscape architecture, studying restrictions and proposing drawings according to the landscape.

As examples of actions that can be applied to urban rivers, the green margins are maintained, with some low-impact urban or landscape uses. The incentive to plant covers with the protection of existing trees and the planting of new trees. The use of native species has priority of choice because they are well adapted to local conditions. Such action reduces the costs of structures for rainwater management, due to its role in water retention. In addition, it prevents flooding, filters out toxins and impurities, extends the availability of water in the dry months, and mitigates the effects of the urban heat island. The existing vegetation in the rainwater path avoids or minimizes erosion, in addition to bringing people closer to the environment that surrounds them, in search of their preservation (Andrade, 2014).

Another important action would be the definition of the limits of permanent preservation areas (PPA) for perennial and intermittent water courses and in this way to recover streams avoiding burying or channeling, which can be associated with linear parks (Andrade, 2014).

Linear parks can act as an environmental and landscape strategy with strong visual and functional appeal to the population, reversing the culture of hiding urban rivers. As an example of this rehabilitation, one can mention the recovery of the Cheonggyecheon River in Seoul, South Korea, showing how the city can modify its conceptions about urban development and restore its natural role. After the restoration, there was a great public approval for the new environmental quality of the city, the reduction of the effect of the city's heat island being one of the project's positive points.

The countless possibilities contained in the multifunctionality of the landscape constitute a factor favorable to socio-ecological resilience, given the diversification and valuation of the services offered by these complex and adaptive systems, the landscapes in their cultural and multifunctional dimensions. Tourism also presents itself as a possibility to deal with changes and contribute to socio-ecological resilience. Tourism industry needs a careful planning to avoid loss of cultural services or loss of environmental quality needed for socioeconomic development (Cunha, 2015).

Riverside communities may depend to a greater or lesser extent on the river's resources for their livelihood. These resources themselves can be diverse and incorporated into tourism, fishing, other extractive uses, and transportation. In general, the economy depends a lot on the aquatic system. If an oil spill affects a tourism location, it will also affect fish stocks and have other ecological impacts, affecting the local balance and requiring readjustment for its livelihood. Therefore, with the study of socio-ecological resilience, it is intended to address the scope of new perspectives on urban water that considers the metropolitan view of the territory, the right to the city, and the resilience of the natural environment, associated with public policies, urban and rural zoning, management of water resources, seeking integration between the landscape and the community.

5 Case Studies

5.1 *Capibaribe Park in Recife*

5.1.1 Thinking and Planning the City Adopting the Capibaribe River as the Backbone of a Water-Centered City

Few centuries ago, Recife City (Brazil) began its first houses at estuarine zone of Capibaribe River and other rivers that share the same estuary. The first long-lasting (and ongoing) conflict is between the city and nature, notably the fight to control water. Recife's identification with the waters of the Capibaribe River, the main watercourse that traverses it, is one of the city's most striking features (Monteiro & Carvalho, 2016).

The Parque Capibaribe project in Recife seeks to rescue the river and its importance to the city. The Parque Capibaribe project foresees revitalization of the Capibaribe River in the urban stretch within Recife as a way of better planning the city. Socio-ecological resilience is being strengthened with the creation of a system of integrated parks on the two banks of Capibaribe along 15 km of the river, including a path for pedestrians and cyclists.

Capibaribe Park will be a large linear park that revolutionizes the way people live in Recife by reconnecting them with the waters of the Capibaribe River, rescuing the hydrographic basin as the backbone of the city through areas of leisure, rest, and well-being (INCITI, 2016).

Currently, in 2020, the Capibaribe Park is in the stage of detailing the project and implementing the first activities. The work being carried out is part of the technical cooperation agreement between the Recife City Hall, through the Environment and Sustainability Secretariat and a multidisciplinary team from the Federal University of Pernambuco (UFPE).

In the urbanization process of Recife, the river channels were strangled due to irregular and even formal occupation of its banks, a process that continues today, endangering the municipality's natural drainage system and resulting in frequent flooding (Cabral et al., 2015). The park's proposals address the need to improve the hydrological, hydraulic, ecological, and social conditions of Recife's urban streams, while enhancing the natural conditions of its surroundings, mobility, and contemplative leisure.

Therefore, Parque Capibaribe also promotes a change in the mentality of the population in relation to the river, taking an innovative look at the countless possibilities of actions in the waters of Capibaribe. The park was not only thought of as a line along the watercourse. It works with a strip of at least 500 meters around each bank, which significantly expands the area of influence of the water courses.

During the process of designing the Capibaribe Park, dialogues were established to listen to the different needs and desires that each reality awakens, through conversations with associations of residents; the elderly; women; youth and children; residents of riverside communities – shellfish gatherers, boaters, and fishermen – street vendors; and people who live in the regions directly impacted by the transformations of the project (INCITI, 2016).

The basic idea is to use the Capibaribe River and its tributaries to plan a green city, which will promote reconnection with nature, through the gradual recovery of waters and riparian forests (Fig. 14.4). The river and the city will become a meeting place and opportunities, through the creation of open, collective, inclusive spaces, in the form of sustainable processes to face the challenges of a changing planet, with both climatic and economic effects (INCITI, 2016).

Various urban solutions are being planned to allow spaces for approaching the river, through footbridges that run along the banks and mangroves and piers that allow the access of small boats. It is expected that people can reach the river, travel it, cross it, and activate actions from the river.

In order to recover the feeling of belonging and ownership of people with the river and the public space, several activities were carried out with the participation of hundreds of people, over several months.

To strengthen socio-ecological resilience, it is necessary for people to participate and one of the ways is with leisure, rest, and festive activities. Figure 14.5 shows one of the activities of a river tour with music during the 2020 carnival.

To strengthen socio-ecological resilience, all those interested in participating were involved in actions to think about the environmental recovery of the river banks, encourage the organization of informal traders in the surrounding area, and develop prototypes of lighting, signage, and urban furniture, in order to transform the territory in an environment of coexistence, leisure, environmental awareness, and contemplation of the landscape (INCITI, 2016).

Fig. 14.4 Planning for the city of Recife in the coming years using the Capibaribe River as the main focus. (Source: INCITI (2016))

Fig. 14.5 River trip with music during the carnival in 2020 year. (Source: authors)

5.2 *Parnamirim Stream*

5.2.1 The Resilience of an Almost Dead Stream That the Community Tries to Revitalize

The Parnamirim stream corresponds to an urban tributary of the Capibaribe River; its hydrographic basin is located in the West Zone of the city of Recife (Brazil) and has a drainage area equivalent to 135.2 hectares (Braga et al., 2009). Its initial stretch suffered from the canalization and currently passes through drainage pipes. Despite that, there is still a stretch, a little more than 1 km long and 5 m wide, in which the stream runs in the open, making possible the revitalization process of this stretch (Cabral et al., 2019).

In the last few years, the stream has suffered many impacts due to the disorderly urbanization process with irregular constructions and untreated sewage discharge. In a study on the Water Quality Index, the results showed the water quality to be very bad, showing high concentrations of biochemical oxygen demand and thermotolerant coliforms and the absence of dissolved oxygen in the water. The release of sanitary sewer was pointed out as the main cause of poor quality (Cometti et al., 2019).

Cabral et al. (2019), aiming at the importance of trophic and ecological relationships that the meiofauna brought to the aquatic environment, carried out a study on the composition of the meiofaunistic community in the hyporheic zone of the Parnamirim stream, and, despite the high degree of pollution in which the stream is found, species of the Oligochaeta and Amphipoda taxa (Fig. 14.6) were found with relative abundance.

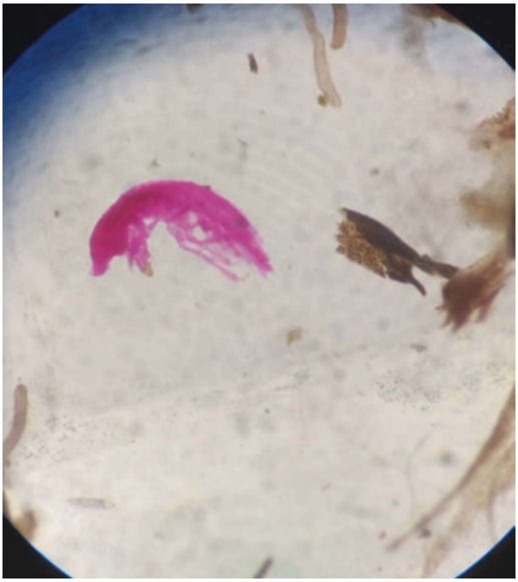

Fig. 14.6 Meiofauna Amphipoda found in the hyporheic zone of the Parnamirim stream. Visualization by a stereoscopic microscope with 4x magnification. (Source: Cabral et al. (2019))

Fig. 14.7 (**a**) Bridge over Parnamirim stream. (**b**) Zoom on the previous photo to show the turtle under the bridge, even in a sewage polluted river. (Source: authors)

In addition to meiofauna, it is possible to observe a macrofauna residing in these streams, which are the turtles. Cavalcanti, Oliveira, and Monteiro (Cavalcanti et al., 2015) carried out a survey of the fauna present in the Capibaribe River, where the presence of turtles (*Phrynops geoffroanus*) was observed in the section where the Parnamirim stream is located and highlighted the ecological aspects such as the adaptation of these animals (Fig. 14.7). Souza (2004) pointed out that this species of tortoises is carnivores and within its diet are fish, crustaceans, and insects; however,

Fig. 14.8 Largo do Holandês besides Parnamirim stream. (**a**) After installation and painting. (**b**) Social meeting at Parnamirim river bank. (Source: authors)

this species is very adaptive and can feed on seeds and fruits, and in environments degraded by anthropic actions, they even eat domestic sewage.

In the last 10 years, teachers and researchers, together with the population, have been carrying out work to raise awareness of the importance of revitalizing the stream, providing information on the advantages of recovering ecological characteristics, such as their role in draining rainwater, thermal comfort, and the environment: aesthetic and the environment for leisure purposes (Cabral et al., 2017; Preuss et al., 2020).

An interesting situation has occurred for the creation of a small square on the banks of the stream where previously there was trash and weeds. The group of residents of the neighborhood developed several actions to improve the place and the city government collaborated with the donation of seedlings to plant and the lighting of the square (Fig. 14.8).

5.3 Fishing Women in Recife City

5.3.1 The Fishing Community of the Tejipió Estuary Represents a Good Example of Socio-Ecological Resilience in the Middle of a Metropolis of 4.5 Million Inhabitants

Across the Brazilian Northeast, around 500 thousand artisanal fishermen are part of food production, reaching 75% of the fish that reach the table of more than one million families from across the region.

In the city of Recife, in Pernambuco, Brazil, there are several fishing colonies, such as the Brasília Teimosa, Ilha de Deus, Coque, and Pina communities. Artisanal fisheries are of great socioeconomic importance in the region due to local ecosystems (mangroves and coastal reefs) at estuarine zone of Capibaribe River, Beberibe River, and Tejipió River which, although they have a small number of species, they are highly productive (Fig. 14.9). According to the latest report by the Center for Research and Management of Fisheries Resources in the Northeast (CEPENE,

Fig. 14.9 Fishermen and canoes at estuary of Tejipió River, collecting sururu in Recife City, at a mangrove area in the middle of a very urbanized region. (Source: Diário de Pernambuco (2019))

2009), the institution responsible for monitoring fisheries production in the northeast, 11,000 professionals are engaged in artisanal fishing, operating a fleet of 2042 units, mostly canoes and rafts, and some motorized boats (Fox, 2010).

Deep sea fishing is generally a male activity, but in estuarine areas, women in fishing communities have been carrying out activities that involve catching fish (fishing with the hand line and small nets, collecting shellfish, oysters, and sururu), the processing of fish (salting of fish, evisceration), the maintenance and repair of fishing instruments (nets, canoe sails), and the marketing of fish (Machado, 2009). Sururu (*Mytella charruana*) is a common bivalve in Central and South America. They are around two centimeters long and generally of brown color.

Based on the analyzes carried out by Cidreira Neto (2019) on tide fishermen, it was possible to observe the forms of interaction between fishermen and the tide, resulting in a network of knowledge and wisdom, built from daily contact with this ecosystem, making each unique know-how, and of relevant importance for the continuity of the activity. Each fishing art is based on a personal expression, based on the practice and knowledge acquired by the most experienced, which is being rebuilt with each new generation that takes on this profession, adapting to the new economic, social, and environmental standards.

Shellfish fishing takes place in estuarine zone in the beach and mangrove areas, mainly at low tide, which allows the appearance of sandy/muddy banks used for collection, being carried out in social or individual groups. There are two main forms of fishing, manual, where shellfish are collected through direct extraction in the sediment and the one with the aid of artisanal equipment which increase the collection capacity (Fig. 14.10) (Silva & Martins, 2017).

Fig. 14.10 Fisherwomen treating sururu, removing the flesh from inside the shells. (Source: Diário de Pernambuco (2019))

Fishing takes place on a small scale of production, handcrafted by fisherwomen, but has great social, economic, and environmental importance. Known as tidal work, regulated by several environmental factors such as changes in salinity, pH, and temperature, fishermen and women in this activity have relevant environmental knowledge, as well as the dynamics of the harvested organism.

From an environmental point of view, as the process takes place manually, it causes minimal impacts. To assure the socio-ecological resilience, it is important to evaluate the effects of pollution, due to the unhealthiness of rivers and mangrove areas, as they can cause the extinction of the activity and the lack of fishing populations.

The work and the way of life earning a living according to the movement of the tide in the estuarine region created some very striking cultural aspects within the city. Thus, the natural space becomes socialized by these individuals; it gains diversified tones and shapes, transforming the inhabited place into an object of manifestation of subjectivities, of the social construction of meanings, and of the assimilation of practices, principles, and values that become the ethos of the community (Caetano, 2015).

In order to improve the socio-ecological resilience of the region and ensure the sustainable exploitation of fishing resources by artisanal fishing, some public policies are necessary avoiding pollution in rivers, financing the purchase of new fishing materials, encouraging tourism for knowledge of local reality, and sustaining social cohesion for the participation of the entire community.

5.4 *Beberibe River*

5.4.1 Beberibe River Presents Socio-Ecological Resilience Only Upstream

The Beberibe River is considered one of the main rivers in the Recife Metropolitan Region (Brazil). Its hydrographic basin has an area of approximately 79 km2. The use of soil in the basin is due to urban and industrial occupation, areas of Atlantic Forest and mangrove, and polyculture. The river water is used for public supply and reception of domestic and industrial effluents. Regarding the industrial activities developed in the basin, there are food products, chemistry, pharmaceutical/veterinary products, drinks, paper/cardboard, metallurgy, and perfumes/soaps/candles. Figure 14.11 shows the Beberibe River basin.

In hydrographic terms, this basin can be divided into three distinct parts which are upper Beberibe, middle Beberibe, and lower Beberibe. The upper Beberibe corresponds to the main course drainage located west of the BR-101 route. The middle Beberibe comprises the stretch between the BR-101 and the confluence with the Morno River. Between the confluence with the Morno River and the Atlantic Ocean, there is the lower Beberibe. To assess the resilience of the Beberibe River, it is important to characterize the following attributes: hydrological/hydraulic function, water quality, and aquatic life.

(a) Hydrological/hydraulic function.

- The upper Beberibe is located in an elevated region, with several perennial springs and covered with vegetation. If measures are not adopted in relation to their form of occupation, this area may suffer a strong process of anthropization, with the consequent increase in the percentage of impervious

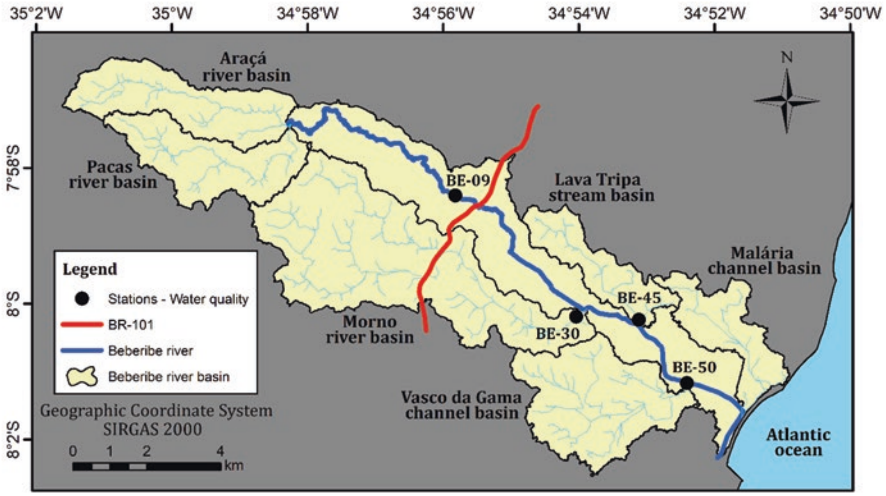

Fig. 14.11 Beberibe River basin. (Source: authors)

areas in that part of the basin with probable consequences of floods downstream.

- The middle Beberibe basin contrasts with the upper section as it presents an open valley, with flat margins, often occupied by water excesses during the rainy seasons. In these margins, the occupation process took place quite sharply, which leads the local population to a permanent condition at risk of flooding.
- The lower Beberibe basin corresponds to the most inhabited portion of the basin. The level of densification and imperviousness of some of the urban agglomerates present in the area is already close to the saturation limit.

Figure 14.12 illustrates the situation of the basin in relation to the process of land use and occupation.

(b) Water quality.

The Water Quality Index (WQI) was used to assess water quality. This index considers quality variables that indicate the release of sanitary effluents into the water body, providing an overview of the surface water quality conditions. The upstream section has good water quality, with low levels of pollution. This category includes bodies of water that present conditions of water quality compatible with the limits established for class 2 of fresh waters, whose

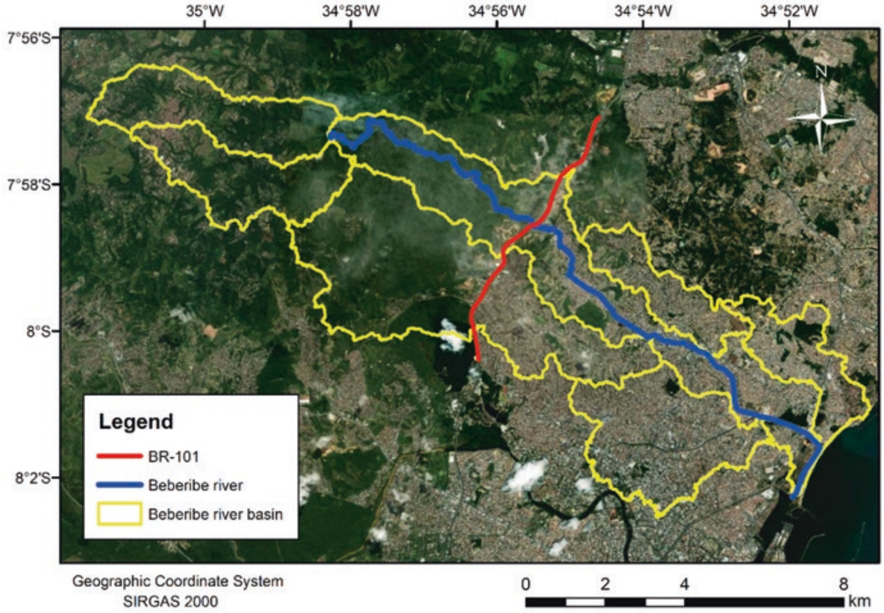

Fig. 14.12 Land use and occupation in the Beberibe River basin. Upstream stretch on the left hand side presents good vegetation cover but downstream on the right hand side is highly urbanized. (Source: authors)

main uses are the supply for human consumption, after conventional treatment; the protection of aquatic communities; recreation of primary contact such as swimming, water skiing, and diving; the irrigation of vegetables, fruit plants, parks, gardens, and sports and leisure fields, with which the public may come into direct contact; and aquaculture and fishing activity (CONAMA, 2005).

Downstream monitoring stations indicate poor water quality, with very high pollution. In this category are bodies of water that do not fit into any of the classes. Therefore, the water quality of upper Beberibe is much better than that of middle and lower Beberibe.

(c) Aquatic life.

The assessment of aquatic life with the Beberibe River was carried out using the Trophic State Index (TSI). The purpose of the TSI is to classify water bodies in different degrees of trophy, that is, it evaluates the quality of the water in terms of nutrient enrichment and its effect related to the excessive growth of algae and cyanobacteria (CPRH, 2020).

Table 14.1 shows the water quality and the trophic state for several monitoring points.

Resilience of Beberibe River: From the analyzed attributes, it is possible to infer that the upper Beberibe shows good conservation features, with characteristics close to natural conditions. For this stretch, it is observed that the river itself has the capacity to recover presenting strong resilience properties. In the middle and lower Beberibe, large impacts are observed, requiring the adoption of measures, such as the implementation of renaturalization projects, which seek to adapt the river to improve its hydraulic, social, and environmental conditions.

6 Conclusions

Resilience can be conceptualized as the ability to recover after an impact, returning to conditions prior to the impact or adapting to new conditions. Watercourses in cities have been highly impacted over the last few decades, leading to the need to better study the resilience of urban rivers and streams.

Table 14.1 Water quality and trophic state for monitoring points at Beberibe River

Parts of the Beberibe River	Station	Water quality	Trophic state
Upper Beberibe	BE-09	Little polluted	Mesotrophic (53)
Middle Beberibe	BE-30	Very polluted	Supereutrophic (65)
Lower Beberibe	BE-45	Very polluted	Eutrophic (63)
Lower Beberibe	BE-50	Very polluted	Hypereutrophic (70)

Source: CPRH (2020)

Engineering resilience in urban rivers presents multidisciplinary characteristics such as hydrology, hydraulics, water quality, erosion, and sediment transport. Each of these aspects can be impacted and resilience can be defined for each of these aspects according to the system's recovery capacity and also according to reduction of probabilities of failures, reduction of the consequences of failures, improvement of recovery conditions, and reduction of recovery time.

The revitalization of rivers improves ecological resilience protecting the health of ecosystems, preserving water resources, and protecting against floods. Two environments are fundamental for the revitalization of rivers: the riparian zone and the bottom zone of the riverbed, known as the hyporheic zone. Riparian zone is considered a transition area for aquatic and terrestrial species helping to regulate ecological functions in both environments. Hyporheic zone is important for nutrient cycling and as a natural filter capable of attenuating pollution at places where river recharge the aquifers.

Linear parks can act as an environmental and landscape strategy with strong visual and functional appeal to the population, reversing the culture of hiding urban rivers. Linear park multifunctional landscape constitutes a factor favorable to socio-ecological resilience, given the diversification and valuation of the services offered by these complex and adaptive systems.

The Parque Capibaribe project in Recife includes a linear park that seeks to rescue the river and its importance to the city. Local mobility solutions are being planned to allow spaces for approach the river and cross or walk along through footbridges, walkways, bicycle paths, and piers that allow people live and enjoy the river. Planning the park had the participation of hundreds of people, over several months to encourage the feeling of belonging and ownership of people with the river.

An interesting example of socio-ecological resilience of urban rivers can be found at a shared estuary of three rivers in Recife (Brazil). At this estuarine area, women in fishing communities have been carrying out activities that involve fishing (with the hand line and small nets); collecting shellfish, oysters, and sururu (a common bivalve in Brazilian northeast); and processing and the marketing of fish. This professional activity has passed through generations and has helped to generate jobs, maintain economic activity, preserve the environment, and contribute to the resilience of the river and the city.

References

Adger, W. N., Hughes, T. P., Folke, C., Carpenter, S. R., & Rockström, J. (2005). Social-ecological resilience to coastal disasters. *Science, 309*(5737), 1036–1039.

Afonso, J. A. C. (2011). Renaturalização e revitalização de rios urbanos: uma abordagem sistêmica. MSc Dissertation, Pontifícia Catholic University, Paraná State.

Ahern, J. (2010). Planning and design for sustainable and resilient cities: Theories, strategies and best practices for green infrastructure. In V. Novotny, J. Ahern, & P. Brown (Eds.), *Water-centric sustainable communities* (pp. 135–176). Wiley.

Anderies, J. M., Janssen, M. A., & Ostrom, E. (2004). A framework to analyze the robustness of social-ecological systems from an institutional perspective. *Ecology and Society, 9*(1), Art18.

Andrade, L. M.. (2014). *Connection of spatial patterns of urban ecosystems: the construction of a method with a transdisciplinary approach to the process of urban design sensitive to water at the community and landscape level*. Thesis, Doctorate in Architecture and Urbanism – Faculty of Architecture and Urbanism, University of Brasília.

Ayres, J. M., Da Fonseca, G. A. B., Rylands, A. B., Queiroz, H. L., Pinto, L. P., Masterson, D., & Cavalcanti, R. B. (2005). Os corredores ecológicos das florestas tropicais do Brasil (No. 333.7516 C824). Sociedade Civil Mamirauá, Belém.

Battin, T. J., Besemer, K., Bengtsson, M. M., Romani, A. M., & Packmann, A. I. (2016). The ecology and biogeochemistry of stream biofilms. *Nature Reviews Microbiology, 14*(4), 251.

Bernhardt, E. S., & Palmer, M. A. (2007). Restoring streams in an urbanizing world. *Freshwater Biology, 52*(4), 738–751.

Binder, W., Werner, A., Castro, D. M., Riker, F., Gelli, G., Lerner, H., & Teuber, W. (2001). *Rios e córregos: preservar-conservar-renaturalizar: a recuperação de rios: possibilidades e limites da engenharia ambiental*. Rio de Janeiro (Brasil): SEMADS. pp. 44.

Braga, R. A. P., Cabral J. S. P., Oliveira, P., Soares, M. A., Gusmão, P. T. R. (2009). Informações Hidráulicas e Hidrológicas para Renaturalização do Riacho Parnamirim. in: XVIII Simpósio da Associação Brasileira de Recursos Hídricos – ABRH. Campo Grande.

Bruneau, M., Chang, S., Eguchi, R., Lee, G., O'Rourke, T., Reinhorn, A., Shinozuka, M., Tierney, K., Wallace, W., & von Winterfelt, D. (2003). A framework to quantitatively assess and enhance the seismic resilience of communities. *EERI Spectra Journal, 19*(4), 733–752.

Cabral, J. J. S. P.; Braga, R. A. P., Fonseca Neto, G. C., Cabral, P. L., & Santos, S. N. (2019) abordagem multidisciplinar no processo de início de revitalização de três riachos da bacia do rio Capibaribe. in: XXIII Simpósio da Associação Brasileira de Recursos Hídricos – ABRH. Foz do Iguaçu.

Cabral, J. J. S. P., Cerquinha, G., Gusmão, M. B. R., & Carvalho, A. F. (2015). Beginning of paradigm change related to urban rivers and streams in Recife city, XXI Simpósio Brasileiro de Recursos Hídricos, Brasília.

Cabral, J. J. S. P., Fonseca Neto, G. C., Cabral, P. L., Martiniano, A. L. R., Monteiro, P. B.C. L., & Braga, R. A. P. (2017). Avanços e desafios para a revitalização de rios urbanos em recife: o caso do riacho Parnamirim. in: XXII Simpósio da Associação Brasileira de Recursos Hídricos – ABRH. Florianópolis.

Cabral, L. N., & Cândido, G. A. (2019). Urbanização, vulnerabilidade, resiliência: relações conceituais e compreensões de causa e efeito. urbe. *Revista Brasileira de Gestão Urbana, 11*, e20180063. https://doi.org/10.1590/2175-3369.011.002.AO08

Caetano, H. S. (2015). Occupation of the territory: Practices and interactions between shellfish gatherers in the fishing environment. *Environmental Management and Sustainability Magazine, 3*(2), 204–222.

Carpenter, S., Walker, B., Anderies, J. M., & Abel, N. (2001). From metaphor to measurement: Resilience of what to what? *Ecosystems (New York, N.Y.), 4*(8), 765–781. https://doi.org/10.1007/s10021-001-0045-9

Cavalcanti, R. S., de Oliveira Melo, L. C., & Monteiro, C. M. G. (2015). Como resgatar a relação da cidade com os ambientes naturais: projeto parque Capibaribe, recife-pe. *Periódico Técnico e Científico Cidades Verdes, 3*(8), 33–48.

Centro de Pesquisa e Gestão de Recursos Pesqueiros do Litoral Nordeste (CEPENE). (2009). Boletim Estatístico da Pesca Marítima Estuarina em Pernambuco.

Chang, C. C., & Turner, B. L. (2019). Ecological succession in a changing world. *Journal of Ecology, 107*(2), 503–509.

Cidreira Neto, I. R. G. (2019). *Tide fishermen: Local knowledge as a subsidy for fisheries management in Northeast Brazil*. Master's Dissertation, Federal University of Pernambuco, Graduate Program in Development and Environment, Recife.

Cometti, J. L. S., Cabral, J. J. S. P., Santos, F. P., & Conceição, T. M. (2019). Avaliação temporal (2016–2017) e espacial do Índice de qualidade da água dos riachos do Cavouco e Parnamirim, Recife-PE. In Sustentabilidade e Responsabilidade Social em Foco: Volume 13/ Organização Editora Poisson – Belo Horizonte – MG, pp. 12–27.

CONAMA (Conselho Nacional do Meio Ambiente), Brasil. Resolução n° 357, de 17 de março de 2005. Diário Oficial [da] União, Brasília, DF, Brazil.

CPRH. Agência Estadual de Meio Ambiente de Pernambuco. Grupo de bacias de pequenos rios litorâneos GL1: Monitoramento das bacias, acessed in 09 jun 2020 at http://www.cprh.pe.gov.br/Controle_Ambiental/monitoramento/qualidade_da_agua/bacias_hidrograficas/resultados_monitoramento_bacias/grupo_de_bacias_gl1/41786%3B67670%3B480301020302%3B0%3B0.asp.

Cunha, N. S. (2015). Socio-ecological resilience and sustainability of tourism in Ilha dos Marinheiros, Rio Grande (RS). Master's Dissertation, Federal University of Rio Grande do Sul (FURG), Postgraduate Program in Geography, Rio Grande.

Del Tánago, M. G., & Jalón, D. G. (2007). Restauración de ríos. Guía metodológica para la elaboración de proyectos. Ministerio de Medio Ambiente. Madrid, Spain, 318 pp.

Diário de Pernambuco. (2019). Ilha de Deus: Marisqueiros perdem a clientela após desastre com óleo no litoral do estado, accessed in 30 may 2020 at https://www.diariodepernambuco.com.br/noticia/vidaurbana/2019/11/ilha-de-deus-marisqueiros-perdem-a-clientela-apos-desastre-com-oleo-n.html

Diner, J. (2017). *Resilience: It is not just for rivers*. Accessed in 30 May 2020 at https://www.americanrivers.org/2017/03/resilience-not-just-for-rivers/

Dole-Olivier, M. J. (2011). The hyporheic refuge hypothesis reconsidered: A review of hydrological aspects. *Marine and Freshwater Research, 62*(11), 1281–1302.

Douglas, E. J., Pilditch, C. A., Kraan, C., Schipper, L. A., Lohrer, A. M., & Thrush, S. F. (2017). Macrofaunal functional diversity provides resilience to nutrient enrichment in coastal sediments. *Ecosystems, 20*(7), 1324–1336.

Empresa de Manutenção e Limpeza Urbana – Emlurb. (2016). *Plano Diretor de Drenagem e Manejo das Águas Urbanas do Recife: Relatório do diagnóstico do sistema de drenagem existente*. ABF Engenharia e Prefeitura da cidade do Recife, Brazil.

Folke, C. (2006). Resilience: The emergence of a perspective for social-ecological systems analyses. *Global Environmental Change, 16*(3), 253–267. https://doi.org/10.1016/j.gloenvcha.2006.04.002

Fox, V. P. P. (2010). *Artisanal fishing and local development: the national fishermen's movement – MONAPE (1990–2009)*. Master's dissertation in rural extension and local development, Federal Rural University of Pernambuco, Department of Education – Recife.

Gregory, S. V., Swanson, F. J., McKee, W. A., & Cummins, K. W. (1991). An ecosystem perspective of riparian zones. *Bioscience, 41*(8), 540–551.

Gunderson, L. H. (2000). Ecological resilience—In theory and application. *Annual Review of Ecology and Systematics, 31*(1), 425–439. https://doi.org/10.1146/annurev.ecolsys.31.1.425

Holling, C. S. (1996). *Engineering resilience versus ecological resilience. Engineering within ecological constraints* (pp. 31–44). National Academy Press.

Holling, C. S., & Gunderson, L. H. (2002). *Panarchy: Understanding transformations in human and natural systems*. Island Press.

Hughes, T. P., Bellwood, D. R., Folke, C., Steneck, R. S., & Wilson, J. (2005). New paradigms for supporting the resilience of marine ecosystems. *Trends in Ecology & Evolution, 20*(7), 380–386.

INCITI. (2016). Pesquisa e inovação para as cidades, Projeto Parque Capibaribe, site: parquecapibaribe.org/projeto. Acessed in 8 June 2020.

Kiley, D. K., & Schneider, R. L. (2005). Riparian roots through time, space and disturbance. *Plant and Soil, 269*(1–2), 259–272.

Kurth, A. M., & Schirmer, M. (2014). Thirty years of river restoration in Switzerland: Implemented measures and lessons learned. *Environment and Earth Science, 72*(6), 2065–2079.

Laboy, M., & Fannon, D. (2016). Resilience theory and praxis: a critical framework for architecture. *Enquiry, 13*(1), 39–52.

Liu, Y., Dedieu, K., Sánchez-Pérez, J. M., Montuelle, B., Buffan-Dubau, E., Julien, F., Azémar, F., Sauvage, S., Marmonier, P., Yao, J., Vervier, P., & Gerino, M. (2017). Role of biodiversity in the biogeochemical processes at the water-sediment interface of macroporous river bed: An experimental approach. *Ecological Engineering, 103*, 385–393.

Machado, M. F. (2009). *Between land and sea: women's work in fishing communities in Brazil*. The Portal of Psychologists.

Merill, L., & Tonjes, D. J. (2014). A review of the hyporheic zone, stream restoration, and means to enhance denitrification. *Critical Reviews in Environmental Science and Technology, 44*(21), 2337–2379.

Miguez, M. G., Rezende, O. M., & Veról, A. P. (2015a). City growth and urban drainage alternatives: Sustainability challenge. *Journal of Urban Planning and Development, 141*(3), 04014026.

Miguez, M. G., Veról, A. P., De Sousa, M. M., & Rezende, O. M. (2015b). Urban floods in lowlands—Levee systems, unplanned urban growth and river restoration alternative: A case study in Brazil. *Sustainability, 7*(8), 11068–11097.

Monteiro, C., & Carvalho, L. (2016). Recife: The popular struggle for a better city. In: Architectural design Brazil: Restructuring the urban. pp. 96–105.

Mugnai, R., Messana, G., & Di Lorenzo, T. (2015). The hyporheic zone and its functions: Revision and research status in Neotropical regions. *Brazilian Journal of Biology, 75*(3), 524–534.

Nagy-Kovács, Z., László, B., Fleit, E., Czichat-Mártonné, K., Till, G., Börnick, H., Adomat, Y., & Grischek, T. (2018). Behavior of organic micropollutants during river bank filtration in Budapest, Hungary. *Water, 10*(12), 1861.

Nazif, S., Mohammadpour Khoie, M. M., & Eslamian, S. (2021). Urban disaster management and resilience, Ch. 7. In S. Eslamian & F. Eslamian (Eds.), *Handbook of disaster risk reduction for resilience, new frameworks for building resilience to disasters* (pp. 157–186). Springer Nature Switzerland AG.

Nyström, M., & Folke, C. (2001). Spatial resilience of coral reefs. In *Ecosystems* (Vol. 4, pp. 406–417). https://doi.org/10.1007/s10021-001-0019-y

Orozco-López, E., Muñoz-Carpena, R., Gao, B., & Fox, G. A. (2018). Riparian vadose zone preferential flow: Review of concepts, limitations, and perspectives. *Vadose Zone Journal, 17*(1). https://doi.org/10.2136/vzj2018.02.0031

Pacioglu, O. (2010). Ecology of the hyporheic zone: A review. *Cave Karst Sci, 36*, 69–76.

Preuss, S. L. C., Cabral, J. J. S. P., Morrison-Saunders, A., Hughes, M., & M & Nunes, A. B. A. (2020). *Understanding community perceptions of an urbanstream before and after a discussion of revitalization possibilities using photoelicitation*. Environment, Development and Sustainability.

Price, M. F. (2002). Panarchy: Understanding transformations in human and natural systems: edited by Lance H. Gunderson and C.S. Holling. Island Press, 2002. *Biological Conservation, 114*(2), 308–309.

Ramey, T. L., & Richardson, J. S. (2017). Terrestrial invertebrates in the riparian zone: mechanisms underlying their unique diversity. *BioScience, 67*(9), 808–819.

Rockefeller Foundation. (2016). *100 resilient cities*. www.100resilientcities.org

Schaper, J. L., Seher, W., Nützmann, G., Putschew, A., Jekel, M., & Lewandowski, J. (2018). The fate of polar trace organic compounds in the hyporheic zone. *Water Research, 140*, 158–166.

Silva, J. S., & Martins, I. X. (2017). Mollusc fishing in intermarea environments in the west of the State of Rio Grande do Norte, Brazil. *Archives of Science of the Sea, 50*(2), 110–118.

Smit, B., & Wandel, J. (2006). Adaptation, adaptive capacity and vulnerability. *Global Environmental Change, 16*(3), 282–292.

Soulsby, C., Malcolm, I. A., Tetzlaff, D., & Youngson, A. F. (2009). Seasonal and inter-annual variability in hyporheic water quality revealed by continuous monitoring in a salmon spawning stream. *River Research and Applications, 25*(10), 1304–1319.

Souza, F. L. (2004). Uma revisão sobre padrões de atividade, reprodução e alimentação de cágados brasileiros (*Testudines, Chelidae*). *Phyllomedusa, 3*(1), 15–27.

Steiner, F. R. (2006). Metropolitan resilience: The role of universities in facilitating a sustainable metropolitan future. In A. C. Nelson, B. L. Allen, & D. L. Trauger (Eds.), *Toward a resilient metropolis* (pp. 1–18). Metropolitan Institute Press.

Tonina, D., & Buffington, J. M. (2009). Hyporheic exchange in mountain rivers I: Mechanics and environmental effects. *Geography Compass, 3*(3), 1063–1086.

Walker, B., & Salt, D. (2006). *Resilience thinking: Sustaining ecosystems and people in a changing world*. Island Press.

Walker, L. R., Walker, J., & del Moral, R. (2007). Forging a new alliance between succession and restoration. In L. R. Walker, J. Walker, & R. J. Hobbs (Eds.), *Linking restoration and ecological succession* (pp. 1–18). Springer.

Ward, A. S., Gooseff, M. N., & Johnson, P. A. (2011). How can subsurface modifications to hydraulic conductivity be designed as stream restoration structures? Analysis of Vaux's conceptual models to enhance hyporheic exchange. *Water Resources Research, 47*(8), W08512.

Wheater, H., & Evans, E. (2009). Land use, water management and future flood risk. *Land Use Policy, 26*, 251–264.

Williams, D. D., Febria, C. M., & Wong, J. C. (2010). Ecotonal and other properties of the hyporheic zone. *Fundamental and Applied Limnology/Archiv für Hydrobiologie, 176*(4), 349–364.