Is Ensuring the Sustainable Implementation of BGI Possible? System Thinking of Urban Rivers as Social-Ecological Systems

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Herlin Chien, Osamu Saito, and Kensuke Fukushi

Abstract

With the mounting pressure of urbanization, how innovative blue-green infrastructure (BGI) can restore the ecosystem services of urban rivers is a timely issue for any densely populated city seeking to improve its resilience and sustainability through ecosystem-based solutions. Yet, the implementation of BGI is not hazard-free. Its success usually depends on a variety of contextual attributes.

By discussing field research on two urban streams in southern Taiwan, this chapter adopts a system thinking perspective to explore, evaluate, and search for the combination of contextual attributes that not only enables the development of sustainable urban rivers but also improves the resilience of cities. In particular, to understand the macro system behavior and the problem of social-ecological misfit are the analytical focuses of this study. By analyzing the mental models of two urban river cases, this study identifies three misfit problems pertaining to the contextual attributes that can inhibit BGI-induced urban sustainability in the long run: (1) the problem of missing feedback, (2) the problem of trade-offs, and (3) the lack of systematic resilience strategies. The advantage of using a system thinking approach is that it allows for the holistic implementation of BGI while reminding policymakers and researchers of the need to craft BGI strategies

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in connection with, rather than in isolation from, social, economic, and political environments. This study also demonstrates the importance of being aware of the dynamic relationship between resource users, public infrastructure providers, public infrastructure, and resource systems.

Keywords

Grey water · System thinking · Social-ecological misfit · Ecosystem services · Nature for Society

5.1 Introduction

Unlike the conventional urban expansion observed in Western society as "sprawl," with a decreasing trend in population density and a tripling of the area under construction (Carruthers and Ulfarsson 2003; Gómez-Antonio et al. 2016), research from the World Bank in 2015 yielded surprising findings in East Asia (World Bank Group 2015). Their publication suggested an outgrowth of population faster than urban physical footprints, resulting in urban areas becoming denser while medium-sized cities gained the greatest population density. To further challenge the sustainability of future urban planning in Asia, Friedmann and Sorensen (2019) warned that new technologies such as rapid rail systems would encourage medium-sized cities to merge into new scales of conurbation already evident in Japan and China and incipient in India, Indonesia, South Korea, Taiwan, and elsewhere. This new and unprecedented trend of urbanization significantly increases the importance of urban sustainability to ensure the well-being of future urban generations, both native and migratory (Seto 2011), in Asia.

Based on recent comprehensive urban sustainability literature reviews (Journals.elsevier.com 2017; Kaur and Garg 2019), dimensions of sustainability in urban settings include being "smart, efficient, green, and socially just." Yet most common approaches aim at addressing urban environmental problems, promoting the efficient use and protection of natural systems of human and urban species; prevention of air, water, noise, and light pollution; and the management of natural resources, notably via blue-green infrastructure (BGI) (Ahmed et al. 2019; Iojă et al. 2018), in the creation of future blue and green cities (Brears 2018). However, the literature also points to problems and barriers to be overcome[1] in harnessing the maximum benefits of innovative BGI for sustainable urban development.

This chapter aims to supplement the abovementioned research to better understand the challenges of urban sustainability and to seek strategies to improve urban planning. In particular, the narrowed focus of this study is to investigate problems created by the reduced proportion of open green and blue space in densely populated

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[1] Blue-Green Cities Research Project (2013–2016), involved by nine UK universities, industry, and local government partner, aimed to investigate how to better harness the benefits of blue-green infrastructure. http://www.bluegreencities.ac.uk/ (accessed on July 10, 2020).

Asian cities (Liao 2019; Wan and Shen 2015) or parts of the cities that were most under pressure and to empirically evaluate how urban river restoration represents unique opportunities for sustainable development by creating and integrating BGI in cities, thus providing multiple social and ecological benefits. Research questions of this study include (1) how dynamics of social-ecological systems (SESs) influence the sustainable implementation of BGI to restore urban rivers, (2) what the systemic fit[2] or misfit is that promotes or impedes the provisioning of urban ecosystem services (UESs), and (3) what the contextual attributes are that can potentially improve BGI-induced urban sustainability in the long run.

To seek answers to these research questions, this study starts with the specific premise that urban rivers are not only a transitional ecosystem (Iojă et al. 2018, p. 217) in space and time but are also contingent on the dynamics of both anthropogenic and natural processes as endogenous/exogenous and fast−/slow-changing variables (e.g., election and climate change). In other words, our goal is to better understand how urban rivers, as SESs, respond and adapt to changes with BGI strategies to improve the resilience of cities. We pursue a system thinking approach focusing on evaluating variability of slow variables (Walker et al. 2012) over time and their gradual interactions, as opposed to static relationship analysis focusing on fast variables and fast feedbacks in action situations (Anderies et al. 2019), which is also important yet less useful to answer our research questions.

The chapter is structured as follows. We begin by discussing how existing literature identified barriers to implementing BGI to improve urban sustainability in general, in urban restoration projects, and the resulting research gap (Sect. 5.2). Next, we design a system thinking-oriented method to evaluate the role of BGI as public infrastructure (Sect. 5.3). The research goal is to (1) understand the macro system behavior of urban river cases and (2) identify systemic misfits that inhibit the implementation of BGI and to derive insights about problems of system resilience based on two empirical urban river cases in Taiwan (Sect. 5.4). We conclude with reflections on the usefulness of the system thinking-oriented analysis to analyze BGI not just as a biophysical component, and we draw attention to the potential human-nature decoupling problem observed in the empirical findings (Sect. 5.5).

5.2 Application of BGI and Its Barriers to Promote Urban Sustainability

The application of BGI is often theoretically framed as a sustainable and novel approach that will save us from the increased intensity and frequency of a changing climate (Ghofrani et al. 2017). Several studies also confirm the multifunctionality of BGI strategies (Lawson et al. 2014; Voskamp and Van de Ven 2015) to increase urban environmental resilience, such as urban flood risk control, with co-benefits

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[2] The use of our “systemic fit” refers to what the literature usually labels as “institutional fit” (Epstein et al., 2015) or social-ecological fit (Guerrero et al. 2015).

including energy savings and improved air quality (Alves et al. 2019) while improving human well-being that is closely related to the creation of societal (O'Brien et al. 2017) and economic welfare (Evans et al. 2019). However, currently, there is far more research discussing the benefits of green infrastructure (GI) in developing a healthier city (Hansen and Pauleit 2014; Da Silva and Wheeler 2017, Figs. 5.2 and 5.3) and less focus from the perspective of blue infrastructure (Iojă et al. 2018). Some studies simply consider water infrastructure as one type of GI (Liao 2019) or an integrated part when one considers the whole natural system as infrastructure (McDonald 2015).

In addition, BGI is certainly no panacea. Like all other infrastructure, the innovation of BGI requires effective implementation and maintenance to successfully deliver the benefits or co-benefits it was initially designed for. Researchers, therefore, are just beginning to explore barriers that impede the healthy introduction and practice of BGI to promote urban sustainability, especially regarding how to better integrate the water cycle with urban design. Aside from scientific and technical barriers, the latest research suggests that social-institutional barriers pose the greatest hindrance to the implementation of sustainable water management Schemes (O'Donnell et al. 2017) due to the fact that BGI is still considered a "novel" intervention compared to traditional gray infrastructure. In a similar vein, social, political, or environmental "uncertainty" is identified by practitioners as major impediments to the implementation of BGI (Thorne et al. 2018). These non-engineered barriers associated with a lack of confidence in BGI are found to inhibit action at a level equal to or greater than engineered challenges. These scientific results also pave the way for practical crafting of green and blue practices as the basis for a circular city to consider "not only technology" strategies but also emphasize the need for social commitment and new ways of organizing and management.[3] Lastly, to mainstream BGI, scholars call for more future case studies on practical BGI implementation (Liao et al. 2017) to identify further barriers and devise strategies for different cities with various social-ecological settings.

5.3 Rationale and System Thinking-Oriented Methods

To address the research gaps and needs discussed above to mainstream BGI and thereby improve urban sustainability and resilience, this chapter adopts an alternative research angle—a system thinking-oriented analysis approach—and develops a mental model to (1) iteratively understand the impact of system behavior on the implementation of BGI in empirical case studies, (2) identify systemic fits or misfits that promote or inhibit the ability of BGI to restore UESs, and (3) discuss strategies to enhance systemic fits and fix misfits to increase the probability of BGI successfully contributing to urban sustainability. The next section details the rationale and

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[3] See "Not Only Technology" section in https://www.urbangreenbluegrids.com/about/green-and-blue/ (accessed on July 13, 2020).

methods of the system thinking approach and mental models adopted and created by this study.

5.3.1 Usefulness of System Thinking

Despite the implication of BGI in complex systems, i.e., SESs (Flynn and Davidson 2016) or resilience systems (Gunderson et al. 2012; Kofinas and Chapin 2009), dealing with countless social and ecological variables that are intentionally or unintentionally influencing the system, there is a paucity of system thinking approaches (Hjorth and Bagheri 2006) to analyze the barriers of implementing BGI and introducing targeted strategies for overcoming barriers. There are, however, a few projects using a system thinking angle to understand how green or gray infrastructure improve the well-being of urban populations (Svendsen et al. 2012) or to enhance urban sustainability in general (Ahmad and Hills 2008; Shen et al. 2009; Tan et al. 2018).

Theoretically, the usefulness of the system thinking approach (Von Bertalanffy 1968), in contrast to static analysis, is to improve our understanding of the reality that is made out of circularly arranged events, instead of a simple and linear relation. The approach is usually based on the identification and modeling of feedback relations, including time delay, that a specific problem is embedded in (Forrester 1961; Sterman 2000). Haraldsson (2004) referred to such an approach as mental modeling, aiming to explicitly map the understanding of the problem and highlight it for others using causal loop diagrams (CLD) with reinforcing (R) or balancing loop (B) and reference behavior pattern (RBP). To generate a mental model of CLD, seven steps were proposed: (1) define the problem and create the system boundaries; (2) ask the question and state the purpose and goals; (3) identify principal actors in the problem; (4) draw a simple causal loop diagram; (5) create RBP; (6) learn and revise CLD; and (7) conclude (Haraldsson 2004, p.40–41).

One of the system thinking-based frameworks designed to evaluate the governance of shared resources and associated infrastructures is the coupled infrastructure system (CIS) (Anderies et al. 2016), which differs from the institutional analysis and development, which focuses on analyzing static relationships between external structures and the capacity of collective action, the so-called action situation (Ostrom et al. 1994). The application of CIS is wide, encompassing one recent study on a classic example of civil infrastructure, highways (Janssen et al. 2019) to study 700 years of adaptive pathways in Mexico City to minimize water risk (Tellman et al. 2018). Such an approach broadens the scope of analysis to go beyond engineering issues and connects it with the integrated social and political drivers at stake. Through the expanded feedback or causal linkages (Mui et al. 2019), the framework helps to explain the targeted problem not only as a result of biophysical processes but also as iterative consequences of choices made by actors in different organizations and their path dependence.

The latest development of the CIS framework involves the attempt to provide a list of verbs to lay the foundation for a general typology and a standardized protocol for representing dynamics captured in CIS (Anderies et al. 2019), the so-called robustness framework. Figure 5.1 shows one example of archetype robustness framework mappings. The framework is formed with several main building blocks—the resource system (RS), the resource user (RU), the natural infrastructure (NI), the public infrastructure (PI), and the public infrastructure provider (PIP). Verbs 1–6 in Fig. 5.1 are regarded as variables for describing dynamic feedback networks based on "subjectivity," indicating the intention behind the action, such as the goal to restrict, collect, or enable. For instance, a "bridge" as a PI "enables" the pedestrian to cross an urban river yet simultaneously "constrains" the ability of the urban resident as the RU to access the river's water resource freely. Figure 5.1 also reminds researchers to pay attention to the effects of exogenous drivers on human, social, natural, and man-made infrastructures.

The robustness of the CIS framework is based on the premise that proper feedback loops generating positive returns, rather than canceling effects, should be functionally established to ensure the resilience and sustainability of SESs. Yet this emphasis on feedback loops, path dependence, and longer-term processes under the influence of institutional change and interactions between resource users and managerial decisions has received inadequate attention (De Moor et al. 2016; Tekwa et al. 2019). To improve our collective ability to avoid failure of shared resource management, scholars have issued a call to advance (through a post-Ostrom agenda) our understanding of the relationships between institutional structures, processes, contexts, and outcomes (Cumming et al. 2020). They also pointed out that although institutional analysis raises the importance of institutional fit, few theories explicitly specify the combinations of social and/or ecological conditions and the elements of institutions that give rise to fit.

5.3.2 Case Selection for Urban River Mental Modeling

The goal of this study is to identify systematic misfits that inhibit BGI to ultimately promote UESs provided by urban rivers and urban resilience in the long run. By regarding BGI-based urban river restoration as a unique opportunity to improve the urban ecosystem service provisioning in densely populated cities and the human-nature coevolution relationship, two successful urban river restoration programs in densely populated Taiwan are selected as the subjects of this empirical case study for mental modeling. Both cases incorporated BGI as major ecosystem-based strategies to cleanse the degraded urban river, create new recreational green space by riverbanks or in constructed wetlands, and revive the urban economic development of selected cities. Thus, the two cases are selected to provide empirical data and real-life social-ecological interactions to improve our understanding and ability to inductively build an urban river system dynamic model while identifying potential systematic misfits as barriers to implement BGI.

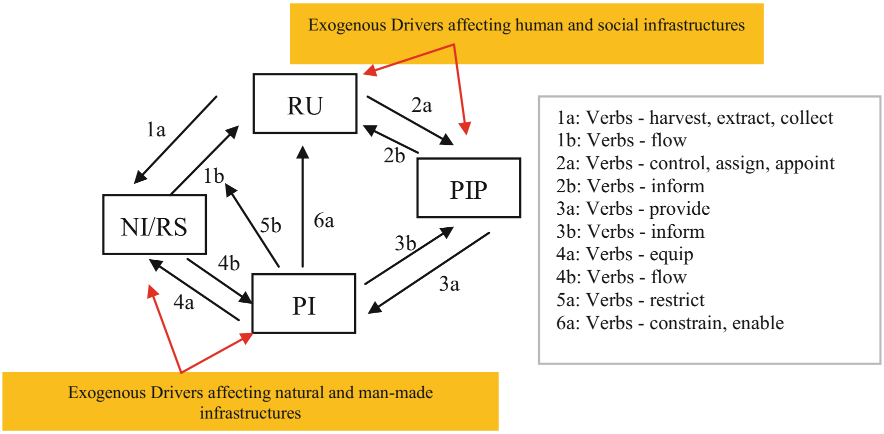

Fig. 5.1 Community governance of shared resource archetype CIS representation sample*. Source: Graph drawn by authors in reference to Anderies et al. (2019) (Figs. 1 and 2, Example 3). *For other SES cases that are the basis of more archetypal models, see System Representation in http://seslibrary.asu.edu

Case A is the Wannian River (Fig. 5.2) in Pingtung City (population density[4] = 3049 per km^2), the second most populated county administrative unit in Taiwan. Case B is Love River (Fig. 5.2) in Kaohsiung City, the second most populated special municipality in Taiwan whose population density[5] (9958 per km^2) is higher than the density of Hong Kong[6] (6690 per km^2). Although the population density in Case A is only one-third of Case B, the Wannian urban river flowing through the city center of Pingtung is also roughly one-third the length of Case B (5.5 km vs. 16 km), and the water quality of both cases for the past decade was classified as moderately polluted (river pollution index of $3.1 < \text{RPI} < 6$ by the Taiwan Environmental Protection Administration, EPA) based on concentrations of suspended solids (SS), biochemical oxygen demand, dissolved oxygen (DO), and ammonia nitrogen (NH_3-N) (Putri et al. 2018).

Despite their different administrative scales, historical context, and social composition, the two cities faced similar environmental challenges created by the reduced proportion of open green and blue spaces in densely populated urban areas. The PIP, namely, the local government in both cities, had made an intentional effort to restore the two respective urban rivers by incorporating BGI strategies,

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[4] 2017 data; see reference in https://den.ncdr.nat.gov.tw/1178/1661/ (accessed on July 13, 2020).

[5] Kaohsiung metropolitan includes urban and suburb section which merged to be single administrative unit in 2010. Since Love River mostly runs through the urban section of the Kaohsiung, the population density calculation used 2010 data before the administrative merge. See Kaohsiung City Government, Civil Affairs Bureau for data access. http://cabu.kcg.gov.tw/cabu2/statis61B2.aspx (accessed on July 13, 2020).

[6] 2014 data from Hong Kong government. https://www.gov.hk/en/about/abouthk/factsheets/docs/population.pdf (accessed on July 13, 2020).

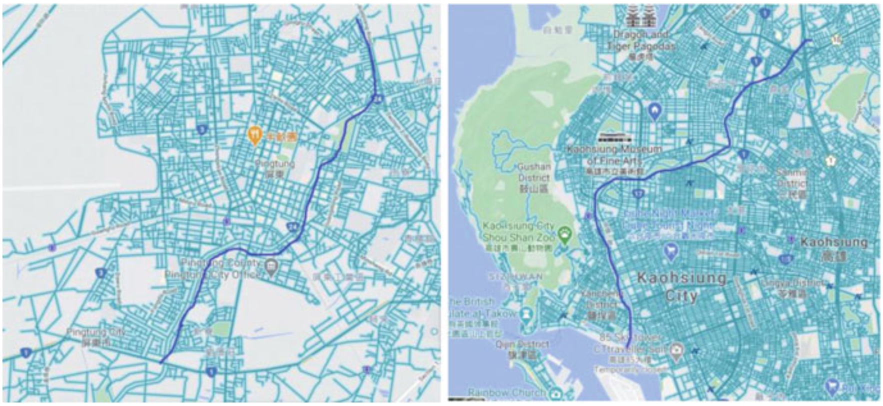

Fig. 5.2 Mappings of the Wannian River (left) and the Love River (right). Source: Drawn by the author with Google Maps as the base map (accessed on February 22, 2021)

including the creation of constructed wetlands and detention ponds as PI (Table 5.1) to purify river water, to minimize flood risk, and to provide extra recreational space. For instance, a total of 23.8 combined hectares of constructed wetlands were added to enhance the ecosystem services of the Wannian River, and a total of 58.1 hectares of BGI were installed for Love River to improve the regulating services and to reduce the flood risk to neighboring communities. These are reasons for comparing the two cases based on the practical implementation of BGI and for identifying their potential systematic barriers to achieving long-term sustainability and resilience and barriers to successfully becoming truly blue-green or ecological cities[7] as envisioned by local authorities.

5.3.3 Steps to Develop and Evaluate Urban River Mental Model

We design four steps to develop and evaluate the urban river mental model—Step 1, operationalizing the data collection; Step 2, drawing a mental map prototype for comparison and backcasting; Step 3, designing system resilience matrix to evaluate the sustainability of system; and Step 4, comparing case studies based on system thinking approach.

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[7] Pingtung City Mayor promoted the city as "ecological city" at Millennia Park where Wannian urban river flows through in 2019. https://www.ptcg.gov.tw/Photo_Content.aspx?n=39A07B9207533EAB&s=ACE0F497F4FD8EA5 (accessed on July 13, 2020); the official vision of Kaohsiung City Government is resilience and green ecological city. See goals in Kaohsiung City Government sustainable development and climate change adaptation committee regulation. https://orgws.kcg.gov.tw/001/KcgOrgUploadFiles/258/relfile/15352/55925/45fbed19-7f13-499f-ae85-e475a1f11b05.pdf (accessed on July 13, 2020).

Table 5.1 Comparison of BGI installation

	Name of BGI (NI)	Area (ha)	Year of establishment
Case A: The Wannian River in Pingtung City	Hai-Fong Wetland	10.3	2009
	Chun-Liao Wetland	11.4	2013
	Golden Wetland	2.1	2017
	Total	23.8	
Case B: Love River in Kaohsiung City	Benheli eco detention pond	37.5	2005
	Love River wetland	0.7	2006
	Heart of Love River	3.1	2007
	Shetzulinbi wetland	4.2	2009
	Jungdu wetland	12.6	2011
	Total	58.1	

Source: Compiled by authors based on interviews and archival data collection

5.3.3.1 Step 1: Operationalizing the Data Collection

Based on the CIS framework and the data available from the two selected cases in Taiwan, this study devises a CIS-UES data operationalization design (Fig. 5.3) to facilitate systematic data collection of urban river governance and its outcomes that serves as the basis for causal mental model drawing in the next step. The model consists of two major types of data, CIS data and UES data, to improve our understanding regarding the effect of resource governance on the performance of ecosystems such as urban rivers. Governance aspects of urban rivers as RS are captured by the following five infrastructures—hard human-made infrastructure (HHMI), soft human-made infrastructure (SHMI), natural infrastructure (NI), human infrastructure (HI), and social infrastructure (SI) outlined in the CIS framework (Anderies et al. 2016). By using CIS as a guideline to disassemble governance of urban river restoration, proxy indicators are designed to quantify each type of infrastructure. For instance, HHMI is a proxy for data collected from government procurement websites specifically dealing with the two river restoration projects; NI refers to the number of constructed wetlands or detention ponds; HI reflects the number of urban river restoration-related nongovernmental organizations or educational facilities. They have similar connotations that are parsed from Ostrom's three external or slow variables—biophysical conditions, rules-in-use, and attributes of the community (AC) (Ostrom 2005).

The outcome of urban river resource governance in this study is represented by UESs provided as an outcome of urban restoration efforts through the application of BGI. Based on the Common International Classification of Ecosystem Service (CICES, version 5.1) released by the European Environment Agency in January 2018,[8] three categories of UESs are assessed by using the best available objective open data: the provisioning service, a proxy for the river pollution index; the

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[8] Release of CICES version 5.1 can be found in https://cices.eu/ (accessed on July 13, 2020).

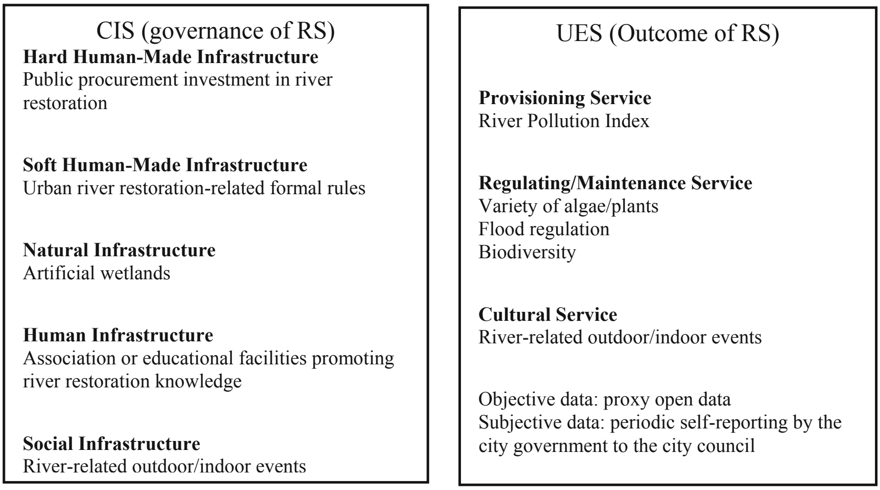

Fig. 5.3 Data operationalization for urban river governance and its outcome

regulating/maintenance service, a proxy for the variety of algae/plants, flood regulation, and biodiversity; and cultural services, a proxy for river-related outdoor and indoor events. To provide further subjective comparisons from the perspective of local governments, periodic reports by city governments to city councils were also collected and analyzed to reveal the self-reporting part of urban ecosystem service performance. The primary data methods used by this study include in-depth interviews and archival data collection (Appendix 1).

5.3.3.2 Step 2: Drawing a Mental Map Prototype for Comparison and Backcasting

Next, in reference to the two selected urban river restoration case studies in Taiwan and the list of verbs provided by Anderies et al. (2019) in Table 5.1 (p. 1904) (based on extant social-ecological system case studies and expert understanding), this study draws a causal mental map similar to but cannot yet be qualified as the standard causal loop diagram[9] to hypothesize a healthy urban river restoration system prototype (Fig. 5.4) as a desirable future for case comparison and backcasting. Considering the CIS framework, each feedback is explained with some demonstrative verbs, which is certainly not a comprehensive list of verbs, contributing positively to the generation of UESs (represented by the green color) provided by the RS.

These positive feedbacks can be further described as balancing or reinforcing loops in the language of system thinking and CLD in future research. However, because of the complexity of variables involved in each listed feedback (1a/b to

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[9] Our current mental map lacks clear "plus" or "minus" signs assigned to all feedbacks as a standard CLD, along with reinforcing or balancing loop indication. See Haraldsson (2004) for a standard CLD.

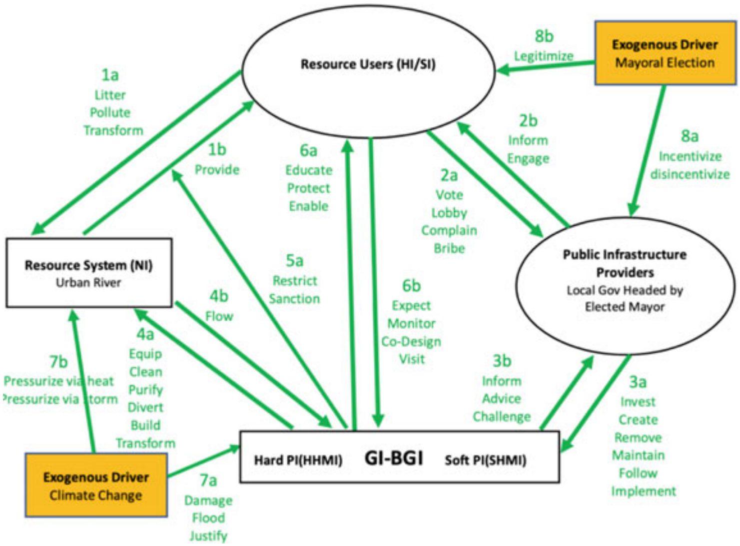


Fig. 5.4 Healthy urban river mental map prototype*. *Depending on various contexts, green represents a balancing (B) or reinforcing loop (R) ensuring a balanced human-nature relationship

8a/b), we acknowledge the limitation of this study. Future research with system thinking or modeling software may further construct the CLD qualitatively and quantitatively to furnish details regarding the status of each feedback loop and its corresponding RBPs. For example, in the feedback of 6a, the BGI of the detention pond as PI "protects" resource users from the threat of flood, in general, enabling ecosystem regulating services. Based on the measurement adopted by researchers, it can be regarded as a "balancing" loop with a plus sign (+) in more creation of detention ponds as PI resulting in a minus sign (−) of RU from the perspective of preventing loss of human asset due to flooding. If contributing negatively to the generation of UESs, the line can be colored as red or as black for unknown or canceling effects. All lines are solid in this visual representation, implying functional feedbacks, whereas missing links can be designated as dashed lines. For demonstration purposes, the thickness of lines is equal in this ideal type, representing reasonable functions in the feedback. Otherwise, a thicker line can signify stronger functionality or more verbs interacting in a specific feedback loop. In contrast, the thinner line signifies a weaker functionality of the feedback.

5.3.3.3 Step 3: Designing System Resilience Matrix to Evaluate the Sustainability of the System

To answer our research question (is ensuring the sustainable implementation of BGI possible?), we need to evaluate the sustainability of the urban river system. We chose system resilience as an indicator, and the main question addressed in this section involves what the characteristics of a resilient urban river system are. In conjunction with indicators developed for the Asian Cities Climate Change Resilience Network

(ACCCRN) funded by The Rockefeller Foundation (Moench et al. 2011), Da Silva et al. (2012; Fig. 5) propose seven characteristics of resilient urban systems: (1) flexibility, (2) redundancy, (3) resourcefulness, (4) safe failure, (5) responsiveness, (6) capacity to learn, and (7) the dependence on local ecosystems. Whereas "flexibility" emphasizes the ability to move beyond business as usual, the ability to evolve and to adopt alternative solutions, and the favoring of "soft" rather than "hard" means for the easiness to change, "redundancy" complements "flexibility" by ensuring multiple pathways and a variety of options to provide and evolve in case one component fails or is disrupted (Godschalk 2003). "Resourcefulness" refers to the ability to mobilize resources, including financial, physical, social, environmental, technological, and information assets. "Safe failure" and "responsiveness" both relate to the system's ability to accept failure and re-establish function to recover from failure. Beyond reorganizing from failure, the "capacity to learn" also expects individuals and institutions to learn from failures. Lastly, the goal is to value the health and stability of "local ecosystems" such as BGI and its role in providing self-organizing ecosystem services for the well-being of natural, social, and economic systems.

This above list adds qualitative elements to the quantitative evaluation of resilience proposed by Bruneau et al. (2003), which focused on only four measures: robustness, redundancy, resourcefulness, and rapidity. In critical infrastructure literature, scholars additionally posit the importance of evaluating resilience qualities according to the interdependence of lifeline systems across technical, organizational, social, and economic dimensions, influencing each other which is an iterative evolution (O'Rourke 2007). Based on the same logic, this study tries to draw an urban river ideal matrix of system resilience (Appendix 2) according to six critical feedback loops specified in the healthy urban river SD prototype (Fig. 5.4), namely, 1a/1b for feedback between the resource system and the RU; 2a/2b for RU and the PIP; 3a/3b for PIP and public infrastructure; 4a/4b for PI and RS; 5a for PI-RS-RU intervention; and 6a/6b for PI-RU. Each feedback loop is reflected independently in the table, yet their interactive effect should not be discounted. The totality of feedback loops should be considered as a cause-effect chain between fluvial dynamics, habitat, ecology (Schiemer et al. 2007), and social community. The list of descriptions included in Table 5.1 is not comprehensive but aims to exemplify what can possibly be done to improve the system of urban river resilience with exemplified descriptions and samples from related research from the past.

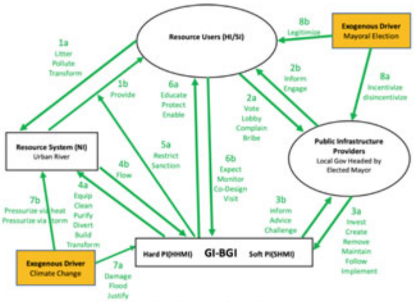
5.3.3.4 Step 4: Comparing Case Studies Based on System Thinking Approach

To reveal the macro system behavior and identify systemic fit/misfit in the two case studies, we create their respective mental models based on the in-depth interviews and compiled archival data (Appendix 1). Then, we conducted two types of comparative analysis: First, to understand the macro system behavior, we compare the two robustness mappings against the healthy urban dynamics mental prototype discussed earlier in Fig. 5.4, where ideally all feedback loops are solid lines with positive effects to improve UESs (denoted in a green color). Second, we also compare the matrix of system resilience for both cases against the ideal matrix (Appendix 2) and determine the most vulnerable part of the system as a barrier to fully implement BGI and as areas for future improvement.

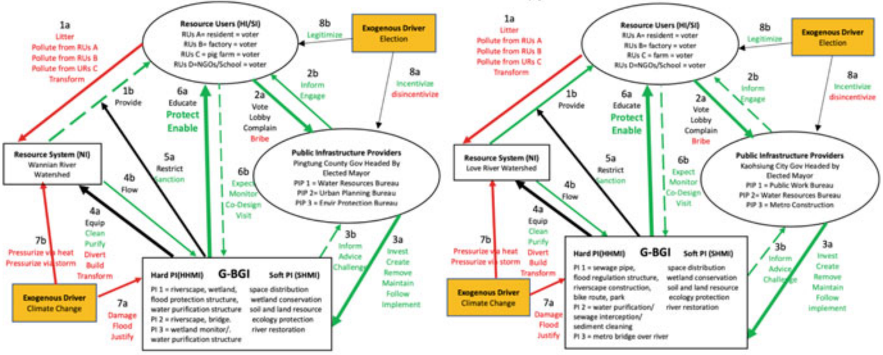
5.4 System Thinking Findings Discussion

5.4.1 Macro System Behavior

In a cursory view, the macro system behaviors of these two distinct urban river restoration cases with BGI intervention are remarkably similar. Both of the right-hand half of the mental model in Fig. 5.5 (green lines between RU-PI-PIP) exhibit all positive feedbacks generating an enhanced river ecosystem service as the balancing loop results. In other words, the logic behind these interconnected balancing loops is that the more local government's investment in blue and green (3a) infrastructure, the more ecosystem services (6a) are generated for resource users (human) and the



Resilient Urban River Prototype



Model A. Model B
(Wannian River) (Love River)

Fig. 5.5 Urban river model robustness comparison. *The green verbs or lines represent positive flow potentially enhancing river ecosystem services; red verbs or lines represent negative flow potentially hindering river ecosystem services; black verbs or lines represent neutral, potentially canceled, or unknown effects. **The thickness of arrows depends on the number of verbs or the degree of impact. ***The dashed line represents a missing link more positive feedbacks and support provided by voters (2a) to the local government as the PIP.

Yet in the left-hand half of the mental model (PI-RU-RS), both cases again unexpectedly exhibit similar balancing loops with more negative or neutral feedbacks—degrading ecosystem services (red line) and unknown or canceled effects (black line). In particular, 1a shows a BGI sustainability problem from a system thinking perspective because more investment in PI including BGI did not deter resource users from repeatedly polluting the urban river (1a in red), i.e., recursively degrading ecosystem service provisioning capability of the urban river as RS (nature). This negatively balancing loop (1a) did not perform in isolation but is connected to how our PI such as a bridge or law often "restricts" (5a in black) the direct contact or interaction between the urban river and resource users such as resident or school. For example, school kids cannot kayak or swim in the urban river without government's special permission in both cities. Thus, the more "restriction" imposed by PI, the more distance is created systematically between urban citizen and nature (missing or weak 1b link) and less urban citizen would pay attention or notice the pollution in the urban river, not generating sufficient public pressure to deter river pollution activities.

Finally, we also did not observe a clear positive feedback loop between the installation of BGI and the quality of the urban river (4a in black) in both cases. Although both local governments made a great effort to install different blue and green infrastructures such as man-made wetlands to purify urban river water or increase green coverage in riverscape hoping to "restore" urban rivers, the water quality of urban rivers was not adequately improved. It is unclear how different public infrastructures create conflicting consequences to the well-being of the urban river (nature). For example, the purposeful diversion of wastewater as a method to improve water quality in rivers results in insufficient inflow and the sudden increase of algae in the river, turning the river into brown or even green color[10] in the summer or dry season. This changing color problem of the urban river can potentially further deter citizens from being close to the urban river and benefiting directly from the urban river's service (1b), indirectly sending the wrong message to factory or pig farm as RU to pollute (1a) this already "unclean" river. The vicious cycle of degrading nature is thus produced for the benefit of human beings.

In brief, the macro system behavior of the two cases demonstrates that the so-called urban river "restoration" endeavor in southern Taiwan, including the installation of BGI by the two local governments, fits more to the "Nature for Society" scenario proposed by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) (Pereira et al. 2020). This means that the river restoration effort creates more utilitarian benefits to people and societies, and does not "restore" the urban river back to its natural status. To establish a more balanced human-nature relationship, in the long run, policymakers might need to

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[10] Changing Color of Love River News June 3, 2020. https://udn.com/news/story/7327/4611421 (accessed on April 20, 2021).

consider how to design a “Nature as Culture” scenario to improve the relational values of nature to promote nature and human in harmony, or even “Nature for Nature” scenarios to rehabilitate the natural habitats for the diversity of species and nature’s ability to function autonomously.

5.4.2 Three Social-Ecological System Misfits

Besides the macro system behavior of urban river cases, there are additional three social-ecological misfits that inhibit the successful implementation of the BGI for the long-term goal of increasing UESs and urban resilience: (1) the problem of missing feedbacks; (2) the problem of trade-offs, and (3) the lack of system resilience strategies.

5.4.2.1 Problem of Missing Feedback

In a close examination of the SD of Models A and B in Fig. 5.5, we can identify three missing links in both models, albeit between different feedbacks. In Model A, feedbacks 1b, 6b, and 3b are missing, and in Model B, the missing links involve 2b, 3b, and 6b. These links, if not fixed, would compromise the robustness of the system and make the system vulnerable to any change or interruption to the system, such as climate change or election. In particular, the first major difference between Models A and B lies in the relationship between the RU (humans) and the RS (nature) where in the current setting, the Wannian River did not “provide” any material or direct service to the residents, factories, or farms in Pingtung City such as edible fish, drinking water, boating, or swimming services. This lack of a direct functional relationship between urban rivers and users reduces awareness as well as the likelihood of users demanding higher river water quality. To fix this problem, nine cities in industrialized countries, such as Boston, Paris, New York City, have initiated “reclaiming river” projects[11] to make polluted waterways into swimming venues. This is similar to what we have observed in Model B, in which Love River hosted triathlons for more than a decade, creating a solid green line between RU and RS. Yet this link is still weak, for numerous individuals were complaining about skin rashes and diarrhea after swimming in the polluted river water.[12]

Secondly, the PIP in Case A, the Pingtung County Government, made comparatively more effort to engage the local community and civil society to implement the Wannian River restoration projects (the solid line of 2b in Model A versus the dashed line of 2b in Model B). According to our interviewees, the Pingtung County Government, under the leadership of Mayor Tsao, had first successfully encouraged the establishment of a nongovernmental organization dedicated to Wannian River

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[11] https://www.curbed.com/2017/8/3/16089352/city-rivers-swimming-safe (accessed on July 22, 2020).

[12] March 22, 2018. News on Love River Triathlon, https://news.pts.org.tw/article/389048 (accessed on July 22, 2020).

restoration (the Wannian River Conservation Association 2009) and then in 2012 further pushed for a Wannian River Protection Family, bringing together up to 37 public and private institutions. Such intentional efforts by the Pingtung local government had strengthened the feedback of 2b between RU and PIP, which is a vital component for bottom-up governance (Girard et al. 2015; Wicaksono 2020) of shared resource management, which was argued to have increased the adaptive capacity toward climate change. This is currently what was missing in the case of Love River, resulting in a missing link on the mapping in 2b.

Lastly, the SD mappings for both cases show missing feedbacks in 6b (RU-PI) and 3b (PIP-PI). 6b describes the ability of the RU to “expect,” “monitor,” “co-design,” or “visit” the PI, including gray and BGI. In Pingtung City and Kaohsiung City, there is no existing large-scale mechanism to voice the expectations of residents toward the various infrastructures installed by the local governments, such as riverbend bike routes or the quality and maintenance of sewage pipes. As for the design of hard or SHMI, such as river conservation acts, opinions of resource users were seldom consulted. The exception might be the hosting of public hearings, which is required by Taiwan law, yet in practice often reflects the expert opinion and does not include enough general user perspective into the policymaking process (Tu 2010)—in other words, the “co-designing” (including “visiting”[13] to better understand our infrastructures) process of involving multiple stakeholders. Furthermore, RU, which is recommended by ICLEI (Local Governments for Sustainability) as a guideline[14] to ensure urban sustainability, is currently absent in both cities. As for 3b, the feedback between PIP and PI is considered to be missing in both cases since there is no evidence of an innovative mechanism for the actors of public infrastructure to “inform,” “advise,” or even “challenge” the elected mayor’s policy decision, which is usually top-down in nature.

5.4.2.2 Problem of Trade-Offs

In the mapping (Fig. 5.5), the two feedback lines are colored as black in both cases, indicating unknown effects or potential trade-off effects between impacts caused by adding gray and BGI to the resource system (4a, RS-PI; 5a, PI-RS-RU). Regarding feedback 4a, since the utilization of BGI or ecosystem-based solutions is a novel practice adopted by local governments in Taiwan, how it can offset the negative impact created by gray infrastructure installed decades ago is still unknown and requires further scientific investigation. Yet, based on the ecological performance of urban rivers in the two cases, scientists and local residents noticed some trade-off problems of GI. The most common trade-off is the positive impact of sewage diversion to lower effluent discharge into rivers, which nevertheless affects the

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[13] To enhance citizen’s knowledge on wastewater interception facilities, Kaohsiung City Government built ten sewer display centers along Love River (Case B). See example in http://mmweb.tw/36512; http://wrb.kcg.gov.tw/loveriver/rebuild.aspx#4 (accessed on July 22, 2020).

[14] Guidelines for co-designing and co-implementing green infrastructure in urban regeneration processes. https://progireg.eu/fileadmin/user_upload/Deliverables/D2.10_Co-design_Guidelines_proGIreg_ICLEI_18-06-20.pdf (accessed on July 22, 2020).

quantity and quality of urban rivers (Huang 2014), especially during seasonal changes with higher temperatures or rain. Historically, during several summers, there have been numerous citizen complaints about the change of Love River water to white, green, or brown[15] colors, as well as large quantities of dead fish in the Wannian River.[16] Despite the Kaohsiung City Government's recent effort to set up information notices explaining the cause of the color change,[17] there might still be room for improvement and reconsidering trade-offs between different PIs. Elsewhere, another trade-off was pointed out by a Kaohsiung City councilor warning of the increased health risk of dengue fever from detention ponds during the dry season[18] when it is not performing its flood risk mitigation function.

Pertaining to feedback 5a, in the relationship between PI, RS, and RU, actors of PI by law issue penalties ("sanctions") on the pollution emitter to discourage pollution. Meanwhile, one of the purposes of PI is to keep RU away (i.e., to "restrict" it) from the river, which would further alienate people from nature (Morgan 2017) for the sake of security (trade-offs) or floodplain regulation-related concerns. Although both local governments have been hosting several "water-familiar activities," most activities were restricted to riverfront areas such as annual lantern festivals hosted in Pingtung City and Kaohsiung City[19] or involved the appreciation of riverscapes, which are considered blue-green or gray infrastructure in this study, rather than directly engaging the RS (i.e., the urban river itself).

5.4.2.3 Lack of System Resilience Strategies

The last systematic governance-ecological misfit observed in the two cases surrounds the deficit of system resilience strategies (Tables 5.2 and 5.3), which is not unusual due to the fact that the resilience principle itself is novel and is only beginning to be experimented upon in recent years.[20] It has therefore not been utilized enough in cities.

In Case A, the most deficient area of resilience strategies involves the relationship between RS and RU (1a/1b) mainly due to the lack of dependence on urban rivers for major services such as fish, irrigation, drinking, or cooling water, resulting in a lack of resource input to try innovative mechanisms or improve responsiveness for demand and supply (red box in Table 5.2). Resilience strategy number 4, safe failure

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[15] https://news.ltn.com.tw/news/life/breakingnews/2801087 (accessed on July 24, 2020).

[16] https://news.housefun.com.tw/news/article/29703768453.html (accessed on July 24, 2020).

[17] https://udn.com/news/story/7327/4611421 (accessed on July 24, 2020).

[18] February 19, 2020, news on change of Love River upstream color into white. https://udn.com/news/story/7327/4356432 (accessed on July 24, 2020).

[19] 2020 Kaohsiung Lantern Festival (https://www.2020khl.com/) hosted in Case B; 2020 Pingtung Lantern Festival featuring animals, https://www.pthg.gov.tw/newyear/cp.aspx?n=BD366C990800F1D0 (accessed on July 24, 2020).

[20] Asian Cities Climate Change Resilience Network (ACCCRN) is one example that was founded in 2008 yet only completed its legacy portfolio of urban climate change resilience (UCCR) in 2016. See more in http://www.acccrn.net/about-acccrn/history (accessed on July 24, 2020).

Table 5.2 Case A system resilience comparison

Case A Quality/Feedback Loop	RS-RU 1a/1b	RU-PIP 2a/2b	PIP-PI 3a/3b	PI-RS 4a/4b	PI-RS-RU 5a	PI-RU 6a/6b
1) flexibility	○	⦿	⦿	⦿	○	○
2) redundancy	○	⦿	○	⦿	○	○
3) resourcefulness	○	⦿	⦿	⦿	⦿	⦿
4) safe failure	○	○	○	○	○	○
5) responsiveness	○	⦿	○	○	⦿	○
6) capacity to learn	○	⦿	○	⦿	○	○
7) dependency on the local ecosystem	○	⦿	○	○	○	○

●, action in place; ⦿, partial action in place; ○, future action required

(gray area in Table 5.2), is also lacking throughout all feedbacks in Case A. Although the city of Pingtung joined ICLEI in 2009 and endeavored to expand its capacity to learn (PI-RS 6: capacity to learn) through abundant international visits and climate change and urban resilience best practice exchanges, the focus of Pingtung has focused more on renewable energy[21] rather than ecosystem restoration. The main resilience strategy for Pingtung County involves transforming the city into a low-carbon exemplary site for Taiwan by completing the carbon disclosure report via CDP cities and developing alternative clean energy solutions. Future effort can be invested into exploring options for ensuring that the urban river system is safe to fail and can recover fast enough from disruption to be resilient. Monitoring the current river quality of the Wannian River, the RPI average showed a surprising trend of continuous degradation from an average of 4.38 during Mayor Tsao's 2009–2014 administration to 4.58 and 5[22] for Mayor Pan's 2014–2018 term. This data indirectly hints that there is no resilience for the system or safe-to-fail mechanism in place that functions well.

A similar continuous degradation of Love River water quality (RPI average 4.73 for Mayor Hsieh's 2002–2006 administration; 4.12 for Mayor Chen's 2006–2010 term; 5.61 for Mayor Chen's 2010–2014 term; 5.50 for Mayor Chen's 2014–2017 administration) and the inability to recover from disruption is observed in Case B where the resilient strategy of "safe failure" (Table 5.3: safe failure for all feedbacks) can also be strengthened in the future. Nevertheless, Kaohsiung City had been flexible enough to adopt innovative BGI, create redundancy such as multiple

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[21] ICLEI programs for Pingtung County, https://lcss.epa.gov.tw/LcssViewPage/Responsive/AreaDoc.aspx?CityID=10013&ActDocId=7a6f193e-0ee2-45a1-b6f1-8297aac07ecf (accessed on July 24, 2020).

[22] Based on data collection gathered by this study based on Pingtung County Government data.

Table 5.3 Case B system resilience comparison

Case B Quality/Feedback Loop	RS-RU 1a/1b	RU-PIP 2a/2b	PIP-PI 3a/3b	PI-RS 4a/4b	PI-RS-RU 5a	PI-RU 6a/6b
1) flexibility	○	○	⊙	⊙	○	○
2) redundancy	○	○	○	⊙	○	○
3) resourcefulness	⊙	○	⊙	⊙	⊙	⊙
4) safe failure	○	○	○	○	○	○
5) responsiveness	○	○	○	○	⊙	○
6) capacity to learn	○	○	○	⊙	○	○
7) dependency on local ecosystem	⊙	⊙	○	○	○	○

●, action in place; ⊙, partial action in place; ○, future action required

detention ponds, invest abundant financial resources, and demonstrate a willingness to learn to achieve the goal of a resilient city. In particular, in 2012, Kaohsiung City collaborated with ICLEI Europe to establish the ICLEI Kaohsiung Capacity Center (ICLEI KCC)[23] as the first East Asian regional training center. As for responsiveness, several Love River patrol groups have been organized and managed by the Environmental Protection Bureau of local governments and have even developed a smoke-free zone by organizing a smoke-free Love River patrol group under the health bureau of the Kaohsiung City Government in 2008.[24]

5.5 Conclusion

This study begins by asking a question in the title: how do we ensure sustainable implementation of BGI? Through adopting a system thinking perspective of analysis, this chapter argues that the success or failure of BGI should not be analyzed in isolation from the social, economic, and political environment it is embedded in. The system dynamics triggers feedback loop effects and shapes and reshapes the problems of SESs, such as the loss of open green and blue space in compact cities and how urban river restoration can be regarded as a window of opportunity to experiment with resilient strategies and BGI-based solutions.

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[23] http://kcc.iclei.org; ICLEI KCC website (accessed on July 24, 2020).

[24] Smoke-free Love River news 2008, https://tw.appledaily.com/headline/20080531/7JV62TFX56ZHGZP6CPGA3PLC2Y/ (accessed on July 24, 2020).

To understand the macro system behavior and identify systemic misfit that promotes or impedes the provisioning of UESs based on BGI applications in urban river restoration, this study bases our analytical findings on two urban river cases in southern Taiwan. Apart from uncovering the Nature for Society macro system behavior, three social-ecological misfit problems are identified and discussed pertaining to contextual attributes that can improve BGI-induced urban sustainability in the long run: (1) the problem of missing feedback; (2) the problem of trade-off; and (3) the lack of systematic resilience strategies. We recognize that most of our empirical work is from specific cities, and they are contingent on local contexts. However, we also believe that their propositions can generate lessons to build urban resilience for other compact cities around the world.

In short, the two empirical cases, albeit different, unexpectedly point to a common problem—the decoupling of humans and nature. This human-nature decoupling includes the lack of direct relationships between urban rivers and resource users (link 1, Fig. 5.5) and the biased emphasis on ecosystem services for human needs such as flood prevention or cultural services (link 6), similar to the Nature for Society scenario proposed by IPBES. It also marginalizes the need for "nature" to be "restored" to its original condition (links 4 and 5), namely, the Nature for Nature scenario in IPBES's conceptualization. The next question we should ask ourselves is "what are we restoring?" and "why are we restoring it?" Recognizing this human versus nature gap in restoration strategies might also have useful applications in cases worldwide. Topics including how to reconnect cities to the biosphere (Andersson et al. 2014) (PI-RS feedback), reclaiming and recirculating urban nature (Yates and Gutberlet 2011) (RU-RS feedback), how to reconcile the temporal difference between changes in political systems, and the frequency of climate change[25] versus the ability of cities to recover from shocks (Richard and David 2018) (RU-PIP-PI feedback), either man-made or natural, are all worthy of our future scholarly attention.

Conflict of Interest Statement The authors report no conflict of interest for this publication.

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[25] Climate change mapping database, https://www.carbonbrief.org/mapped-how-climate-change-affects-extreme-weather-around-the-world (accessed on July 24, 2020).

Appendix 1: Technical Note on Data Collection

Case Study	A: Wannian River[a]	B: Love River
Data collection period	November 2019–January 2020	January 2020–March 2020
Method 1	13 in-depth interviews with local government officials and civil society stakeholders were conducted to provide background information for CIS-UES prototype model building	1 visit to water engineering bureau to understand the background and problems of Love River with several staff in march of 2019 to assess the case selection and data collection process 1 in-depth interview with senior staff at Kaohsiung. Bird association who assists to manage Jungdu wetland in march of 2019 to assess the case selection and data collection process
Method 2	Government archival data systematic collection – Local government's periodical reports to city council 2006–2019 for 100 entries – Public procurement data 2006–2019 for 123 entries – River water quality monitoring data 2010–2019 for 121 entries – Regulation data – Other technical reports provided by local governments or downloaded from website, such as wetland biodiversity reports or lantern festival data summary	Government archival data collection systematic collection – Local government's periodical reports to civil council 2006–2019 for 803 entries – Public procurement data 2001–2019 for 399 entries – River water quality monitoring data – Regulation data 1999–2019 for 1765 entries – Other technical reports provided by local governments or downloaded from website, such as wetland biodiversity reports and flood regulation reports
Method 3	Social/news data systematic collection – Citizen report news archive 2009–2019; search keywords: Wannian River = 100 news – Google search for Wannian River-related events/organizations mentioned in the above reports	Social/news data systematic collection – Citizen report news archive 2007–2019; search keywords: Love River = 83 news – Google search for Love River-related events/organizations mentioned in the above reports

[a] More in-depth interviews were planned for Wannian River as prototype of CIS-UES model

Appendix 2: Urban River Ideal Matrix of System Resilience

Feedback loop quality	RS-RU 1a/1b	RU-PIP 2a/2b	PIP-PI 3a/3b	PI-RS 4a/4b	PI-RS-RU 5a	PI-RU 6a/6b
1. Flexibility	Identify and try new solutions to treat or dilute wastewater and to enjoy river (Gambhir et al. 2012)	Identify and try new ways of open data/ engage citizen (Petts 2006)	Identify and try new combination of gray infrastructure and BGI (Mulligan et al. 2020)	Identify and try new ways of purifying (Edmundnt 2000), transforming urban river, and feeding back monitoring data (Baird and Hajibabaei 2012)	Relax law to enable citizen benefiting more ecosystem services provided by urban river (Robbins 2018)	Identify and try new ways to educate, protect, enable, expect (Sakamoto et al. 2018), monitor, co-design (Bradford et al. 2018), and visit
2. Redundancy	Various options to litter, pollute, provide	Multiple channels to complain/ lobby/ inform/ engage citizen/ prevent rent seeking	Various options to inform/ advice/ challenge/ invest/create/ remove/ maintain	Various options to equip/clean/ purify/diver/ build/ transform/ inform	Various options to ensure safety of using and benefiting ecosystem services provided by urban river	Various options to educate, protect, enable, expect, monitor, co-design, and visit
3. Resourcefulness	Provide technique to process waste and benefit from river's resource	Provide funding/ leverage ICT to vote/ lobby/ complain/ inform/ engage/ prevent rent seeking	Provide funding to monitor performance of BGI	Assemble team to monitor urban river and its associated ecosystem	Provide infrastructure and technique to enable services of urban river to human	Have laws and policies ready to educate, protect, enable, expect, monitor, co-design, and visit
4. Safe failure	Ability of regulate rate of waste discharge and equip river to absorb waste at slower pace	Respond to part of complaints/ inform and engage part of citizen/ lower probability of rent seeking	Accept minor damage of BGI	Minimize trade-off impact caused by gray infrastructure and BGI on urban river	Control of GI and BGI to absorb waste at slower pace	Ability of system to allow minor mistakes and experiment made by co-designing
5. Responsiveness	Rapidity to restore river's services after disruption, i.e., pollution and transformation	Rapidity to inform/ engage/ lobby/ complain	Rapidity to fix and recover damage of BGI (Fekete 2019)	Rapidity to report (Cairns Jr et al. 1970) and fix problems associated with ecosystem of urban river	Rapidity to punish polluter and to permit services to human when available	Rapidity to fix minor mistakes made by co-designing experiment
6. Capacity to learn	Best practices and failures of living with urban river and benefiting from urban water[a]	Best practices and failures of open governance (Bingham 2006)	Best practices and failures of BGI and PPP (Takahasi 2004)	Systematic record of urban river ecosystem performance/ best practices and failures of urban river ecosystem restoration	Maintain record of polluters and learn to enable ecosystem services of urban river to human	Best practice and failure sharing to educate, protect, enable, expect, monitor, co-design, visit

(continued)

Feedback loop quality	RS-RU 1a/1b	RU-PIP 2a/2b	PIP-PI 3a/3b	PI-RS 4a/4b	PI-RS-RU 5a	PI-RU 6a/6b
7. Dependency on local ecosystems	Increase value and invest to maintain healthiness of river ecosystem	Promote perceived value of local ecosystems among citizen and elected mayors (Andersson et al. 2014)	Ensure different offices appreciate multiple values of local ecosystems	Ensure actors of PI recognize multiple ecosystem services provided by urban river and their trade-off and synergy (Han et al. 2017)	Ensure actors of PI recognize importance of sanctioning polluter and a healthy ecosystem to lower need to restrict use of urban river	Facilitate RU's recognition of multiple ecosystem services by BGI and encourage co-design of BGI to ensure healthiness of local ecosystem

[a] See best practice examples in http://www.ecrr.org/River-Restoration/Urban-River-Restoration (accessed on July 19, 2020)

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