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Chapter 18
Resilience Management for Healthy Cities in a Changing Climate

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Abstract Cities are experiencing multiple impacts from global environmental change, and the degree to which they will need to cope with and adapt to these challenges will continue to increase. We argue that a 'complex systems and resilience management' view may significantly help guide future urban development through innovative integration of, for example, grey, blue and green infrastructure embedded in flexible institutions (both formal and informal) for multi-functionality and improved health. For instance, the urban heat island effect will further increase city-centre temperatures during projected more frequent and intense heat waves. The elderly and people with chronic cardiovascular and respiratory diseases are particularly vulnerable to heat. Integrating vegetation and especially trees in the urban infrastructure helps reduce temperatures by shading and evapotranspiration. Great complexity and uncertainty of urban social-ecological systems are behind this heatwave-health nexus, and they need to be addressed in a more comprehensive manner. We argue that a systems perspective can lead to innovative designs of new urban infrastructure and the redesign of existing structures. Particularly to promoting the integration of grey, green and blue infrastructure in urban planning through institutional innovation and structural reorganization of knowledge-action systems may significantly enhance prospects for improved urban health and greater resilience under various scenarios of climate change.

Keywords Resilience management · Nature-based solutions · Urban health · Climate change · Urban complexity · Knowledge-action systems

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Highlights

- Cities are experiencing multiple impacts from global environmental change.
- A systems perspective can lead to innovative designs of new urban infrastructure and the redesign of existing structures to address complex urban health challenges.
- The integration of grey, green and blue infrastructure in urban planning through institutional innovation and structural reorganization of knowledge-action systems may result in large health improvements and increase urban resilience.

18.1 Introduction

Urban health and well-being is an outcome of urban complexity. In this chapter we argue that cities are complex adaptive social-ecological-technological systems, a perspective needed in order to untangle this complexity and define the types of problems we are confronted with (Alberti et al. 2018). By framing complexity conceptually we suggest pathways for urban governance for urban health and well-being, pathways that address problems of great scientific and economic complexity and radical uncertainty, of which climate change is a prime example. One example of such a pathway is using multiple ecosystem services as a means to create resilience to climate change in cities and thus reduce negative impacts on health and well-being, or so-called 'nature-based solutions' (NBSs) (Secretariat of the Convention on Biological Diversity 2009), such as the 'Sponge City' initiative for flood water treatment currently taking place in China and the green roof design thriving across many European cities. Whereas technology can be helpful for solving complicated engineering problems by seeking solutions for optima and equilibria, complex or inexact problems require the recognition of deep uncertainty and non-linearity.

18.1.1 Urban Systems as Complex Adaptive Systems

A social-technological approach has, up until now, been the traditional way of analyzing urban complexity (e.g. Geels 2011; Hodson and Marvin 2010), and in this context, many have struggled to define exactly what is meant by a city. Here we expand on an emerging framework of cities as complex *social-ecological-technological* systems, as cities include much more than a particular density of people or area covered by human-made structures (Bai et al. 2016; Alberti et al. 2018).

Cities are places where social, ecological and technological systems connect and integrate; where various types of capital and infrastructures intersect in multi-dimensional spaces; and where connectivity, interaction, exchange and communication accelerate in time. Urban socio-ecological-technological systems are complex and dynamic because multiple agents from various types of networks interact with each other and their environments, and on multiple scales (Table 18.1). The health and well-being outcomes that emerge from these complex adaptive systems are not entirely plannable (Alberti et al. 2018).

Urban systems (which include social, technological and ecological dimensions) provide functions (Table 18.1) that are similar but not identical to those provided by ecosystems (Gatzweiler et al. 2016, 2018).

A key difference between urban and natural ecosystems is that most goods and services in urban systems are produced by people and are a result of secondary production, while natural ecosystems consist of primary (autotroph) and secondary producers. Nevertheless, recognizing cities as complex adaptive systems that provide numerous categories of functions (Table 18.1) is the basis for resilience management for healthy cities in the context of climate change.

Table 18.1 Functions of urban systems

Function	Description
Supporting	Benefits provided by physical space (habitat) and infrastructure for basic life support functions such as waste management, water treatment and sanitation, and energy provision (electricity). Enables the flow of energy (captured in the form of low-entropy goods) and information. They are necessary for all other functions to be produced. Markets sometimes require physical space for exchange, but market exchange can also take place in virtual spaces
Provisioning	Benefits derived from providing manufactured goods and knowledge, and providing infrastructure for access to water, energy, food, transportation, social interaction and market exchange to maintain the population's health, internal structure, procedures and processes; e.g. (processed) food, (purified) drinking water, construction materials, machines, artifacts (e.g. furniture, bicycles), education and knowledge infrastructure (universities)[a]
Regulating	Benefits derived from providing rules and regulation mechanisms to keep the infrastructure running; e.g. regulating access to social space, legal systems and markets (although not exclusive to urban areas, their significance may often be higher here because of higher institutional density and economic activity in urban areas). The means are laws, norms, cooperatives, law enforcement, disease and disaster management and emergency response systems, hospitals and health service systems, and environmental protection agencies
Cultural	Benefits provided for humans in cities that are created in socio-cultural spaces (again not exclusive to cities). Social space and liberties for economic and political exchange, exchange of ideas, social exchange, recreation and leisure, space for spiritual enrichment, art and cognitive development; e.g. cultural events, "Heimat" (sense of belonging), exhibitions, libraries, cultural heritage values (e.g. historical places), cultural diversity

[a]*Note:* The raw materials and natural resources, like oil, gas and wood, are also used directly in cities; however, that is rather a provisioning function of natural ecosystems

18.1.2 Urban Complexity, Sustainability and Governance

The complexity of urban systems poses enormous challenges for sustainability in identifying causal mechanisms because of the many confounding variables that exist. At the same time, scientific findings from empirical studies are difficult to generalize due to variations in socio-economic and biophysical contexts, and the great heterogeneity that characterizes urban regions (Grimm et al. 2008). Key challenges are scale mismatches, cross-scale interactions and limited transferability across scales (Cumming et al. 2012). Furthermore, the limited predictability of system behaviour over the long term requires a new consideration of uncertainty (Polasky et al. 2011).

The research and application of urban sustainability principles have until now rarely been applied beyond city boundaries and are often constrained to either single or narrowly defined issues (e.g. population, climate, energy, water) (Marcotullio and McGranahan 2007; Seitzinger et al. 2012). Although local governments often aim to optimize resource use in cities, increase efficiency and minimize waste, cities can never become fully self-sufficient. Therefore, individual cities cannot be considered ‘sustainable’ without acknowledging and accounting for their dependence on the natural ecosystems, resources and populations from other regions around the world (Folke et al. 1997; Seitzinger et al. 2012). Consequently, there is a need to revisit the concept of sustainability, as its narrow definition and application may not only be insufficient but can also result in unintended consequences, such as the ‘lock-in’ of undesirable urban development trajectories (Ernstson et al. 2010).

Governance failures and their negative outcomes can at least partly be understood as the result of a constrained ability and willingness to understand the dynamics of urban complexity. Governing dynamic complex urban systems for improving urban health and well-being, therefore, requires a better understanding of urban system complexity and the institutions that inhibit or enable solution-oriented actions (cf. Duit and Galaz 2008).

The dynamics and temporality of changes of a system determine adaptive governance styles. Under short-term shocks or longer-term stresses the styles of action can be control-oriented or adaptive (Fig. 18.1). Control-oriented styles of governance

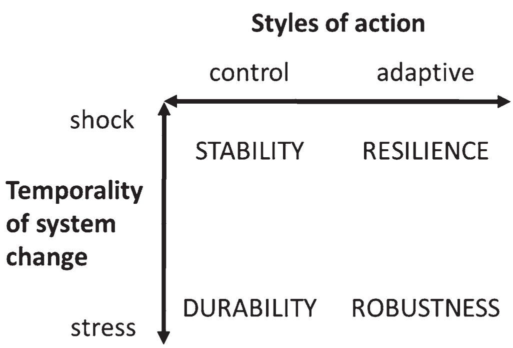

Fig. 18.1 Governance styles are determined by control and adaptive styles of action and how the temporality of system changes is perceived. (Modified from Leach et al. 2010)

assume less uncertainty and more calculable risks. Under such governance, stability (against shocks) or endurance (against stresses) of a system are believed to be maintained or restored by actions of control and order. Recognizing the inherent uncertainty of complexity also acknowledges limits to a control-style of governance.

Managing the resilience of an urban system for health depends on how system changes are perceived and on whether controlled or adaptive, flexible actions are performed (Fig. 18.1). The co-production of knowledge for urban health resilience management and integrated systems of flexible governance for urban health are responses to urban complexity and an attempt to harness it for sustainability.

The World Health Organization's Global Outbreak Alert and Response Network[1] is an example of governance strategies for resilience. It is set up to respond to unpredictable external shocks (outbreaks) with a flexible response network that can be mobilised when needed. Another example of resilience management for health is the Epidemic Intelligence and outbreak responses provided by the European Centre for Disease Prevention and Control (ECDC) to the EU Member States. ECDC continuously monitors and assesses epidemic outbreaks in the EU region. In case of emergencies and response needs, ECDC provides both assessment missions and different levels of epidemic response actions. An example of integrated, flexible systems governance for urban health in the context of climate change are the urban Knowledge-Action Systems (KAS) analysed by Muñoz-Erickson et al. (2017). KAS are social networks of actors involved in the production, sharing and use of knowledge for action and all other types of infrastructure, facilitating the flow of resources, including data and knowledge, and thereby enabling feedback, response and learning for action. Such KAS, once institutionalised as an organisational entity, could be referred to as the collective mind of a city, or the 'urban brain'. An example is the Southeast Florida Regional Climate Compact,[2] which came together to upgrade their resilience knowledge systems for climate adaptation.

18.1.3 Urban Complexity and Resilience

When people think of urban resilience, it is generally in the context of response to sudden impacts, such as a hazard or disaster recovery (see Alberti et al. 2003; Alberti and Marzluff 2004; Vale and Campanella 2005; Cutter et al. 2008; Wallace and Wallace 2008). However, the resilience concept goes far beyond recovery from single disturbances, as demonstrated by the above example of knowledge-action systems. Resilience is a multi-disciplinary concept that explores persistence, recovery, and adaptive and transformative capacities of interlinked social and ecological systems and subsystems (Holling 2001; Folke et al. 2002; Walker et al. 2004; Biggs et al. 2012).

[1] https://extranet.who.int/goarn/

[2] http://www.southeastfloridaclimatecompact.org/about-us/what-is-the-compact/

Resilience thinking is part of systems thinking in complexity science, and has two central foci: one is to strengthen the current social-ecological-technological system to live with change by enhancing the ability to adapt to potential external pressures, in order to retain its essential functions and identity; the other is the ability to shift development pathways from those that are less desirable or unsustainable to ones that are more desirable or sustainable –also referred to as transformability (Walker et al. 2004; Folke et al. 2010).

A distinction is often made between general resilience and specified resilience (Walker and Salt 2006). General resilience refers to the resilience of a system to all kinds of shocks, including novel ones, whereas specified resilience refers to the resilience 'of what, to what' – in other words, resilience of some particular part of a system (related to a particular control variable) to one or more identified kinds of shocks (Walker and Salt 2006; Folke et al. 2010). While sustainable development is inherently normative and positive, this is not necessarily true for the resilience concept (Pickett et al. 2013). For example, development may lead to traps that are very resilient and difficult to break out of. The desirability of specified resilience, in particular, depends on careful analysis of resilience 'of what, to what' (Carpenter et al. 2001) since many examples can be found of highly resilient systems (e.g. oppressive political systems) locked into an undesirable system configuration or state. It also may refer 'to whom' as a recognition of environmental inequity (e.g. Pickett et al. 2011).

In general, both the sustainability and the resilience concepts (particularly general resilience) are not easily applicable to the city scale (Elmqvist et al. 2013a). Cities are centres of production and consumption, and urban inhabitants are reliant on resources and ecosystem services – including everything from food, water and construction materials to waste assimilation – secured from locations outside of cities. Although cities can optimize their resource use, increase their efficiency and minimize waste, they can never become fully self-sufficient (Grove 2009). For that reason, it is not sufficient to de-couple cities from resource use (UNEP 2013), rather, cities need to be re-coupled with the regional and global ecosystems in which they are contained (Zhu et al. 2017). Therefore, individual cities cannot be considered "sustainable" without acknowledging and accounting for their teleconnections (Seto et al. 2012) – in other words, the long-distance dependence and impact on ecosystems, resources and populations in other regions around the world (Folke et al. 1997).

Virtually all living systems from the local to the global scale are open and interconnected networks. To achieve resilience for urban health, there is a need to better understand the health and well-being effects of interventions at multiple scales of complex urban systems (Brelsford et al. 2017). Further, as Markelova and Mwangi (2012) point out, referring to Cash and Moser (2000), it is necessary to ascertain the appropriate scale for evaluating benefits from complex systems, and choosing the appropriate scale depends on numerous factors such as the specific objectives of a study, the level of accuracy, and the value system chosen by the evaluator. In addition, interventions will not be effective "when a particular problem issue is managed at an institutional scale whose authoritative reach does not correspond with the geographical scale or particular spatial dynamics of a (…) problem".

However, despite the complex nature of urban systems, there exist relatively simple universal laws that are useful to be aware of when designing systems of governance for urban health resilience. One refers to the urban scaling effect and similarly counts for living organisms. It says that the bigger the organisation becomes, the less energy per capita is needed. For cities, this means that with a doubling of population size, energy supply, for example, increases sublinearly by 85% (one petrol station can serve more people), implying an economy of scale savings effect of 15% for energy and infrastructure. With regard to average wages, the amount of crime and incidence of infectious diseases, the number of patents produced, or the number of restaurants, there is a superlinear scaling effect of 1.15, manifesting systematic increasing returns to scale (West 2017, Bettencourt et al. 2010).

18.2 Climate Change Aggravating Existing Urban Complexity

Demographic and technological changes have resulted in anthropogenic forces on the climate system, greatly exacerbating the flow of energy and materials within urban systems, increasing the complexity levels of urban systems and their functions. In addition, climate change aggravates the complexity of urban systems by imposing direct and indirect impacts on the urban system variables and their functions. Climate change effects include increased intensities and frequency of rainfall, droughts, storms and heat waves, due to warmer sea and land surface temperatures, rising sea levels and reduction of albedo, which further exacerbates the warming, and a range of climate uncertainty. These effects challenge the sensitivity of each variable of the urban social-ecological systems and subsystems (da Silva et al. 2012). The geo-demographical change shows an overall trend of increasing population in increasingly multi- and intercultural urban areas, which challenges the already precarious concept of sustainability of urban systems. The different magnitudes of climate change, therefore, accelerate and complicate both the general and specified resilience of urban systems of multiple scales.

Resilience as a concept has been argued frequently for the case of climate change for the reasons presented above. It is also primarily referred to as the adaptation of climate change impacts. As urban systems are composed of complex environments in which ecological, social, cultural and economic factors interact on multiple scales and across different subsystems, climate change imposes not only direct impacts on the grey, green and blue infrastructure in urban systems, basic life support functions and manufactured goods, such as food, water, energy, transportation and their management and provision, but also indirect impacts on the health and well-being of urban dwellers. Therefore, we argue that health should be an end goal of climate change adaptation and a proxy to examine the level of resilience of complex urban social-ecological-technological systems. Comprehensively acknowledging the value of ecosystem services, incorporating them into urban planning practices for climate change impacts, and institutionalizing this process can help us achieve this end goal.

18.3 Climate Change, Urban Ecosystems and Health

Despite the fact that "…human health is better now than at any time in history…" (Haines 2018), this progress has come at social and environmental costs such as increasing inequality, increasing energy use and related greenhouse gas emissions, soil degradation, biodiversity loss and severe water stress. Together with increasing urban population pressures, this mixture can become a backlash to what we may perceive as progress in human development. In 2012 approximately 7 million people died prematurely as a result of exposure to air pollution, making air pollution the world's largest single environmental health risk. Despite improved availability of health systems and other public services, urban health risks remain: exposure to noise, water and air pollution, diseases related to urban lifestyle, contagious diseases connected with crowding (e.g. tuberculosis, sexually transmitted diseases, influenza, and certain rodent- and vector-borne diseases such as dengue fever, etc.), and risks associated with homelessness, violence and inequality. Understanding the complex interactions of climate change, urban system functions and health has been identified as a research priority for cities in the future (Bai et al. 2018).

Climate change will have numerous impacts on human health and well-being in urban environments depending on local conditions and vulnerabilities. The risk of deaths, injuries and epidemics (especially water-, food-, rodent- and vector-borne diseases) from storms, coastal storm surges and floods will increase in disaster-prone areas, exacerbated by damages to important infrastructure and societal services. Cities are particularly vulnerable to heatwaves since temperatures in certain parts of a city can reach several degrees higher than in surrounding peri-urban and rural areas, due to the so-called urban heat island effect (Zhang et al. 2017). It has been shown that the risk both of death and of acute episodes of chronic diseases, such as acute respiratory illness, heart attacks and stroke, increases markedly in relation to heat wave events (Michelozzi et al. 2009). The elderly, persons with chronic cardio-vascular and respiratory diseases, and individuals who have difficulties implementing heat-reducing actions during a heat wave are particularly vulnerable, and so are outdoor workers in cities where temperatures may soar during working hours (IPCC 2014; Kovats and Hajat 2008). It is well known that air pollution increases the risks associated with heat, and vice versa, which further increases health risks from heat waves in cities.

The urban ecosystem service and urban social-ecological-technological approach have recently developed into several programs exploring the scope and potential of nature-based solutions (Kabisch et al. 2016). Nature-based solutions are actions that are inspired by, supported by or copied from nature, and often with the potential to address a variety of societal challenges in sustainable ways, and contribute to green growth (EU DG Research and Innovation 2015). Nature-based solutions for sustainable urbanization rely in large part on natural areas and features in and around cities to perform essential ecosystem services. This concept may also be used in climate change adaptation to reduce climate change-related impacts on health (Gill et al. 2007), or to gain health co-benefits from climate change adaptation within other sectors of society.

Urban green areas and vegetation can reduce some of the environmental health risks within the urban systems (Elmqvist et al. 2013b). Urban green and water areas, such as city gardens and ponds, and nearby forests, lakes and sea, have a strong potential to locally buffer heat extremes (Hardin and Jensen 2007). In summertime, high temperatures are absorbed by water areas. Greenery, in particular trees, reflects solar radiation and lower temperatures locally through evapotranspiration and shading (Bowler et al. 2010). By increasing urban vegetation through the planting of trees, creating parklands, green rooftops, green walls, and so on, local temperatures in cities can be better regulated and maintained. Urban greenery has also been shown to be effective in reducing air pollutants such as particles and nitrogen and sulphur oxides (Hartig et al. 2014).

Not only do urban green and blue areas reduce health risks associated with high temperatures and air pollutants, but urban vegetation also contributes to reduce flood-related health risks. Vegetation stabilizes the soil and reduces surface runoff following precipitation events. Keeping or adding vegetation will decrease the risk of landslides, as well as the pressure on drainage systems around human settlements. By increasing the vegetation cover and reducing the impermeable surface area in built environments, the volumes of surface storm-water runoff can decrease, thus increasing the resilience to flooding. Increased urban green space will thus increase permeability and water runoff mitigation, as well as decrease flood risk by intercepting rainwater (Pataki et al. 2011).

In addition, urban vegetation has other beneficial health effects. Several studies have shown that vegetation contributes to reducing noise pollution and creating tranquil environments for conducive to mental health (González-Oreja et al. 2010). Urban green areas and vegetation support and facilitate human health and well-being by alleviating stress and allowing space for physical activity and community interaction, which sustain mental health, physical fitness and cognitive and immune functions (WHO 2017).

As the fundamental ecological base of urban social-ecological systems, biodiversity and ecosystem services play a significant role in reducing the negative impacts of climate change on health, both at present and in the future, therefore reducing vulnerability and strengthening resilience of the urban systems and subsystems.

18.4 Organizing Resilience Management for Urban Health

Lessons from the knowledge of complexity science for urban health and well-being (Gatzweiler et al. 2018) have taught us that "a system for governing knowledge and action would need to have as much variety in the actions it can take as exists in the system it is regulating". That means organizing resilience management for urban health needs to respond to some inherent features of complex urban systems. Complex urban systems are not only multi-dimensional, they are multi-sectoral, and the functions they provide (Table 18.1) provide goods and services that have private, public and common pool features.

Nature-based solutions to urban health under climate change are capable of addressing the required variety of such complex urban systems. Resilience management for urban health must combine and link the components addressed above:

1. Knowledge of urban system functions, climate change and health
2. Nature-based solutions (action)
3. Monitoring and impact evaluation
4. Learning and adaptation.

Setting up and governing knowledge-action systems (Fig. 18.2) is a response to the need for solving urban health risks by resilience management. This can be and is being done by scientific analysis of complex urban systems, involving stakeholders in the co-production of knowledge, and implementing that knowledge in decision-making processes. Setting up and governing knowledge-action systems requires: (1) recognition of all urban inhabitants as the stakeholders of urban health, and (2) collective learning. For all urban inhabitants – policymakers, business managers, scientists, citizens and communities – not only are their health and well-

Fig. 18.2 Managing resilience for urban health by implementing and governing of knowledge-action systems

being compromised under climate change, they themselves are also (partially) accountable for the climate-health problems, and, therefore, should be included in resolving them. In addition to knowledge co-creation, policy co-design and implementation and actions to respond to urban climate-health challenges based on the three-dimensional principles of nature-based solutions, governing knowledge-action systems, also requires collective learning. The outcomes of nature-based interventions need to be monitored and observed by stakeholders as feedback to the knowledge pool of climate change, urban ecosystems and health, thereby enabling knowledge-action systems governance, also known as resilience management for urban health, to co-evolve with the changing complexity of urban systems resulting from further impacts of climate change.

18.5 Conclusions

Urban health and well-being outcomes are the product of systems that function to produce services of value to humans. The degree to which urban system functions deliver services for human health and well-being depends on the human capability to manage complexity and create healthy urban environments. Institutions, understood as being made up of rules enabling and constraining interactions, provide the space and freedom for action as well as the organisational constraints.

As human dominance of ecosystems spreads across the globe, humankind must become more proactive not only in trying to preserve components of earlier ecosystems and services that they displace, but also in imagining and building new kinds of ecosystems and nature-based hybrid solutions that allow for a reconciliation between human development, functioning ecosystems and biodiversity. To address this, we offer the following five approaches:

1. *Resilience management for healthy cities* in the context of climate change must be based on a deep understanding of the *complexity of urban systems* and the functions they provide.
2. Climate change affects all urban system functions directly or indirectly, and thereby also human health and well-being. *Urban green areas and greening of other types of infrastructure* need to be planned and managed to respond to the increasing health risks of climate change in cities.
3. *Nature-based solutions* have been developed as an action response to increase resilience to environmental stresses and can be used to *help reduce health risks* of climate change in cities.
4. Managing resilience in urban systems requires *adaptive and flexible governance* styles on several scales in order to enhance multi-functionality of systems and functions that support urban health and well-being.
5. Our knowledge of urban system complexity and urban system functions needs to be translated into actions that are not only nature-based, but also governed by *knowledge-action systems* that recognize all urban inhabitants as stakeholders and enable collective learning for urban health under climate change.

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