Urban social-ecological innovation: implications for adaptive natural resource management

Abstract

The urban landscape, as home to the majority of the global population, has been the scene of significant and lasting ecological degradation. Consequently, modern cities rely on distant and geographically vast areas for the provision of a range of important ecosystem services. Urban centres also, however, comprise important hubs of human invention and innovation. Collective approaches to the use and management of green space in urban social-ecological systems, as a form of social-ecological innovation, provide a valuable resource in the production and adaptive management of local ecosystem services. Urban social-ecological innovation (USEI), therefore, comprises an important consideration in urban environmental governance. Research on innovation in urban social-ecological systems is analysed here and an evaluation of the insights thereby derived culminates in the development of a conceptual framework. We propose that such a framework can be applied by practitioners and researchers alike to evaluate the mediating nature of USEI towards increasing the resilience of productive urban landscapes.

Introduction

Historically, cities have been centres of human innovation and creativity (Capello, 2001; Dvir and Pasher, 2004), and the scene of significant and lasting environmental degradation (Stein et al., 2000; MEA, 2005; Marzluff, 2008; McKinney, 2006; 2008; CBD, 2012; Aronson et al., 2014; Hassan and Lee, 2015). Today's cities face major challenges such as population rise, climate change and diminishing non-renewable resources (Childers et al., 2015). Specifically, assertions have been made in the social-ecological literature that the devolution of highly centralised approaches to natural resource management, a re-focus on collaborative networks and the decentralisation of governance ought to be beneficial from a natural resource management perspective (e.g. MEA, 2005; Andersson et al., 2007; Biggs et al., 2010; UK NEA, 2011). In light of these major challenges, collective management of common green spaces by urban residents has been posited as one approach that may be a key factor in the building of more resilient cities (Ernstson et al., 2008; Colding and Barthel, 2013).

Much of the research exploring collaborative, non-hierarchical modes of natural resource management in the past twenty years has focused on community-based natural resource management (CBNRM) as a promising framework for adaptive management in the face of complexity and uncertainty (e.g. Leach et al., 1999; Shackleton et al., 2002; Armitage, 2005; Gruber, 2010). Collaborative approaches such as CBNRM are predicated on the assumption that devolution of the decision-making process in natural resource management, to include communities and stakeholders, is more likely to foster knowledge and commitment towards sustainable use of those resources (Armitage, 2005). CBNRM, therefore, operates at the interface of top-down and bottom-up approaches and involves primarily the formation of novel institutions and inter-institutional arrangements as the defining innovation (Ostrom et al., 2002). The principal innovation here is, therefore, one related to new forms of governance and, as a result, critical discussion of the merits of CBNRM has likewise focused on the efficacy of institutional design principles and the influence of social processes (Stern et al., 2002; Blaikie, 2006; Cox et al., 2010). CBNRM is, therefore, characterised by an emphasis on collaboration, specifically that between traditional, bureaucratic agencies of environmental governance with communities and stakeholders (Armitage, 2005). As such, collaborative approaches like CBNRM, although novel in comparison with more traditional centralised approaches, stand in contrast to more spontaneous forms of environmental management such as civic ecology and urban community gardening movements which are characterized by their self-organising, emergent qualities rather than their inclusion in collaborative planning processes (Krasny and Tidball, 2012; Middle et al., 2014; Dennis et al., 2016a).These community-led practices involve the mobilisation of end-users in the direct management of natural elements in the urban environment and they have been documented through various narratives and methodologies and under numerous definitions of involvement. The term urban social-ecological innovation (USEI), as employed in this paper, describes activities stemming from the wide array of urban ecological movements which have been described through a broad and often complex social-ecological nomenclature including: civic ecology (Krasny and Tidball, 2015), urban environmental movements (Barthel et al., 2013), social-ecological innovation (Olsson and Galaz, 2012) and organised social-ecological innovation (Dennis et al., 2016a), community-based urban land management (Svendsen and Campbell, 2008), user participation (Dennis and James, 2016a), urban greening (Westphal, 2003), collectively managed urban gardens (Dennis and James, 2017a), community gardening (Hynes and Howe, 2004) and community agriculture (Barthel and Isendahl, 2013).

Although diverse in terms of form and function, ranging from place-based activities such as urban agriculture and community horticulture (Barthel et al., 2010) to more activist movements such as guerrilla gardening (Adams et al., 2015) and from small- to large-scale conservation projects (Krasny and Tidball, 2015), these innovative activities share two defining attributes. These are related to i) their collective, self-organising nature (Bendt et al., 2013; Andersson et al., 2014) and ii) their emergent quality within social-ecological systems (Krasny et al., 2015). On this basis, studies, for example Bendt et al. (2013) and Dennis et al. (2017a), have emphasized the notion of USEIs as communities of practice (Wenger, 2000) representing spontaneous adaptive responses to environmental conditions (Krasny and Tidball, 2012; Dennis et al., 2016a). That they are spontaneous implies they are not the result of governmental intervention but rather are grass roots innovations. Here we delineate intervention as those processes more akin to CBNRM where, for example, consultation with communities leads to more sustainable resource management, such as is being promoted by the neighbourhood planning process in the UK (DCLG, 2016). In contrast, we describe innovation as those activities and movements which involve mobilisation at the community level by innovator-actors towards the management of common-pool resources. Although that which we describe as USEI may involve cooperation with other agencies and authorities, and ultimately influence local and regional environmental policy (Krasny and Tidball, 2015) it may equally be the result of tension and conflict with such bodies (Krasny et al., 2014) and is characterised primarily as a self-organising phenomenon (Holling, 2001). In brief, we delineate USEI here as community-led action in contrast to community-based approaches. The potential for adaptation and self-organisation associated with USEI suggests the latter may be of particular relevance to the notion of resilience in social-ecological systems, a powerful tool for understanding the behaviour and integrity of complex adaptive systems (Folke et al., 2002).However, whereas theoretical and evidence-based evaluations of collaborative, decentralised approaches to environmental governance have a long history (Leach et al., 1999; Ostrom et al., 2002; Shackleton et al., 2002; Gruber, 2008; Cox et al., 2010), the scientific literature has only just begun to explore the landscape-scale distribution and productivity of innovations of a social-ecological nature within the urban environment (Janssen et al., 2006; Dennis et al., 2016a). Evidence has been presented separately on the social (Rosol, 2012), ecological (Dennis and James, 2016a), governance (Krasny and tidball, 2012) and geographical (Dennis et al., 2016) characteristics of USEIs but the conceptual integration of these various aspects has not yet been achieved. Furthermore, whereas conceptual models have been provided which explain the complex dynamics behind the governance, economic and resource-related components of social-ecological systems (Pickett et al., 1997; Rennings, 2000; Ernstson et al., 2008), none exist to date which explicitly define the role of social-ecological innovation in the resilience of urban natural resource management.

It is important to bring together the various strands of knowledge on this topic as, in accordance with the conclusions of resilience theory (Gunderson and Holling, 2002; Anderies et al., 2004), diverse social-ecological innovator networks and the decentralisation of natural resource management may hold some of the keys to adaptive urban management into the future.

Innovation in the context of resilience in urban social-ecological systems

Social-ecological innovation has been described previously in research on social-ecological systems from a resilience perspective. For example, Olsson and Galaz (2012) present the phenomenon in the context of adaptive management and describe it as effective innovation of a social-ecological nature which builds on social learning, crosses levels of governance and encourages broad participation. The principles upon which Olsson and Galaz (2012) describe the merit of such innovation are underpinned by resilience thinking: a systems approach to understanding adaptive cycles in human-dominated environments acting across multiple physical and temporal scales (Gunderson and Holling, 2002). The concept of the adaptive cycle is central to how social-ecological systems behave and is characterised by four phases (Gunderson and Holling, 2002). A growth and exploitation (r) phase relates to the rapid exploitation of resources and is followed by a conservation (k) phase where resources and their management are consolidated and conserved in increasingly efficient, uniform ways. Systems, thereby, slowly become more connected, inflexible and responsive to external shocks making them more susceptible to collapse. When such collapse occurs (Ω phase) this signifies the start of a period of reorganization (α phase) representing the point at which innovation can influence future trajectories or means of re-exploiting environmental resources. Self-organisation is, therefore, a hallmark of adaptive social-ecological systems and the components of those systems which promote regeneration and adaptation (Folke et al., 2002).

The adaptive cycle is a tool for conceptualising social-ecological systems rather than a description of their component parts. Furthermore, systems can be defined according to the scale at which they are studied and entry into the “collapse” phase (Ω phase), for example, can occur in the context of the whole system or components thereof. Moreover, collapse can result from large sudden disturbances such as natural disasters or from more gradual “slow-burn” processes which typically describe social-ecological decline in urban areas (Krasny and Tidball, 2013). The ability to navigate the inevitable stages of this cycle is often referred to as the resilience of a given system (Holling, 2001; Folke et al., 2003). However, inconsistency abounds in the social-ecological literature in the use of and reference to the concept of resilience and closely related terms such as adaptive capacity, transformability and sustainability (Brand and Jax, 2007; Strunz, 2012; Folke, 2016). Moreover, seen as the capacity to persist through environmental change, it is clear that resilience can in fact be a desirable or undesirable property of social-ecological systems depending on whether transformation is seen as a positive or negative proposal.

Attempts to address such inconsistency, and bring clarity to the application of the concept of resilience in social-ecological systems research, have been presented periodically by some of the founders of the resilience thinking approach. In this paper we adhere to the definitions provided by these authors and, in particular, by Folke (2016). These clarifications (put forward separately by Walker et al. (2004), Folke et al. (2002) and Folke (2016)) provide a delineation of two important definitions of resilience, one relating to the overall characteristics of a given system (general resilience) and a second which relates to the targeting of specific management goals (specific resilience).

Innovation and general resilience

The first of these, *general resilience,* has been used in reference to the ability of a system to navigate the adaptive cycle inherent in social-ecological systems (Folke et al., 2010) and is defined by Walker et al. (2004)

and Folke (2016) as being subject to three determining factors: resilience, adaptability and transformability. These authors describe resilience as the ability to undergo disturbance whilst maintaining the same basic functions, adaptability as the ability of core actors within the system to influence resilience, and transformability as the capacity to assemble an essentially new system when the current one becomes untenable.

In order for social-ecological innovation to influence general resilience it must demonstrate a diversity of responses (Folke et al., 2005; Elmqvist et al., 2003; Walker et al., 2006) to unique social-ecological conditions (Olsson and Galaz, 2012; Dennis et al., 2016a). The latter are key to understanding how social-ecological innovations may succeed, or fail, in building on resilience (Obrist et al., 2010). For example, failure of innovation to emerge in a given social-ecological landscape may result from a combination of environmental conditions which lead to social-ecological traps (Carpenter and Brock, 2008). Generally speaking these arise as either self-reinforcing feedbacks in efficient and highly consolidated systems which inhibit flexibility and ability to respond to change (rigidity traps) or as low levels of social or ecological capital (e.g. loose social networks, lack of leadership or high habitat fragmentation) which dampen the flow of information, species, novel ideas or resources (poverty traps). Identification, anticipation and avoidance of such traps are critical to ensuring the capacity for innovation (Biggs et al., 2010).

Innovation and resilience of ecosystem services

Specific resilience in social-ecological systems relates to the targeting of discrete management goals (Folke et al., 2010) in which the content and context of resilience is explicitly defined. In other words, specifying the resilience of what to what? (Carpenter et al., 2001; Liu, 2014). Resilience, as a framework for navigating complex social-ecological systems has become increasingly concerned with the management of ecosystem services (Barthel et al., 2010; Olsson and Galaz, 2012; Biggs et al., 2012). Accordingly, resilience, as it appears herein, implies the ability a system to withstand internal and external fluctuations which may compromise existing levels of ecosystem service provision. Biggs et al. (2012) identified seven core principles of the resilience approach which, if applied, lead to the optimal adaptive management of those valuable ecosystem services provided by social-ecological systems. These suggested principles are: i) maintaining diversity and redundancy; ii) managing connectivity; iii) management of slow variables and feedbacks; iv) fostering understanding of social-ecological systems as complex adaptive systems; v) encouraging learning and experimentation; vi) broadening participation and vii) promoting polycentric governance systems. The resilience approach to the management of ecosystem services, therefore, emphasizes learning and adaptation and, as such, strives for long-term integrity of social-ecological systems, even at the cost of productivity (i.e. terms of ecosystem service provision) (Levin et al., 2013). As such, the promise of social-ecological innovation towards the specific resilience of ecosystem services is focused on its ability to foster learning and experimentation (Folke et al., 2005; Walker et al., 2006; Cumming et al., 2013) and manage "slow" variables. The latter are closely linked to regulating (in contrast to provisioning) ecosystem services such as water cycling processes and climate regulation (Biggs et al., 2012), as well as social processes such as the build-up of local ecological knowledge and learning (Barthel et al., 2014), and institutional change (Ernstson et al., 2010). Innovation may also provide important adaptive responses to environmental stressors (Walker et al., 2006; Elmqvist et al., 2003). As the goal of resilience thinking in social-ecological systems, and likewise that of social-ecological innovation, becomes increasingly focused on the provision of ecosystem services (Shultz et al., 2015), the outlook shares common ground with other prominent frameworks currently driving environmental policy and research, namely the green infrastructure (GI) and the natural capital (NC) approaches. The contribution of urban social-ecological innovation must also be considered and understood within the context of these frameworks if it is to be effectively evaluated and integrated within urban environmental management.

USEI and Green infrastructure

The GI approach comprises two conceptual aspects; firstly, the biophysical components which comprise the green and blue patches and corridors in the urban matrix; secondly, the management approach to maximising the social-ecological integrity of, and benefits issuing from, the configuration of those components (Benedict and McMahon, 2006). Consideration of the first of these two aspects invariably relates to maximising connectivity, diversity and multi-functionality in the physical landscape (Lafortezza et al., 2013, Lovell and Taylor, 2014) and for this reason, a GI approach is particularly relevant to urban areas where habitat fragmentation and degradation render managing for connectivity and multi-functionality highly important (Hansen and Pauleit, 2014; Kabisch, 2015). With reference to the second of these aspects, urban areas are equally suited to the application of a GI approach given that the recipients of the benefits issuing from the latter reside increasingly in towns and cities. Subsequently, a GI approach has been readily adopted in urban research and planning towards maximizing physical productivity and connectivity of natural resources and associated delivery of ecosystem services (Ahern, 2007; Norton et al., 2015; Meerow and Newell, 2017). However, despite this spatial emphasis, early proponents presented the approach as a holistic attempt to manage land conservation with the potential to encompass the socio-economic as well as ecological goals and challenges associated with land-use planning (Weber and Wolf, 2000; Benedict and McMahon, 2006; Weber et al., 2006). To some degree an emphasis on the role of societal needs and influences on natural resource management has been implemented within the GI approach through the adoption of ecosystem services as a primary management goal (e.g. Tzoulas et al., 2007; Lovell and Taylor, 2013; Andersson et al., 2014). However, despite featuring in policy implementation and extensive work exploring the operationalization of GI in urban areas (e.g. Gill et al., 2007; Young and McPherson, 2013; Liquete et al., 2015; Garmendia et al., 2016; Vierikko et al., 2016) there remains a dearth of analysis of USEI from a GI perspective save for a few notable examples (e.g. Ahern, 2011; Lovell and Taylor, 2014; Ahern et al., 2014).

The identification of social-ecological innovation as a key ingredient of a multi-functional green infrastructure approach to the management of ecosystem services, in common with a resilience thinking perspective, has drawn on its ability to facilitate participation and learning. For example, Ahern et al. (2014) put forward a transdisciplinary and participatory green infrastructure planning model based on a “learning-by-doing” approach to promoting innovation through safe-to-fail experiments. Likewise, stakeholder participation in urban greening was presented in Lovell and Taylor (2013) as a critical factor towards the promotion of adaptive urban landscapes through multi-functional green infrastructure. However, where a focus on innovation appears in green infrastructure-based initiatives, it is promoted largely through the model of stakeholder consultation (e.g. Roe and Mell, 2013; Ugolini, 2015; Connop et al., 2016; Wilker et al., 2016). Such a consultation-based approach has much in common with the CBNRM and, as such, stands in contrast to examples of civic ecological practices and stakeholder-led natural resource management which feature in case-studies of social-ecological innovation found in the resilience literature (Ernstson et al., 2008; Rosol, 2010; Barthel and Isendahl, 2013; Bendt et al., 2013; Andersson et al., 2014). These latter cases typically involve greater broadening of participation in and de-centralization of management than is achieved through consultation-only approaches to stakeholder involvement and, in that sense, shares more in common with the CBNRM approach.

Such stakeholder-led natural resource management can involve extensive and complex social-ecological networks and a key area of research on USEI has involved exploring issues such as the balancing of connectivity and centrality in social networks towards adaptive natural resource management (Bodin et al., 2006; Janssen et al., 2006; Ernstson et al., 2010). However, in contrast to resilience thinking, urban green infrastructure stresses primarily landscape, as opposed to social, connectivity towards maximizing the efficient production, and supply and demand, of ecosystem services (CIWEM, 2010; Schäffler and Swilling, 2013; Demuzere et al., 2014; Hansen and Pauleit, 2014; Kim et al., 2015). Moreover, a green infrastructure perspective, with its focus on multi-functionality (Madureira and Andresen, 2014) and productivity (Lovell and Taylor, 2013; Viljoen et al., 2015), seeks to generate benefits by way of "fast" variables (e.g. direct-use ecosystem services such as recreation and food production) but may overlook the importance of managing functional redundancy and slow variables. Furthermore, a consideration of feedbacks and "traps" inherent in adaptive social-ecological systems, which influence the emergence or impedance of innovation (Dennis et al., 2016), is less well-developed in GI frameworks. Conversely, research conducted through the lens of resilience thinking, with a general focus on long-term adaptive capacity, may under-consider potential trade-offs in fast variables which provide direct use benefits to urban residents (such as micro-climate regulation and air purification) upon which a multi-functional GI approach to planning is typically based (Liquete et al., 2015). We propose, therefore, that USEI, as an innovative, diverse and multifunctional use of green infrastructure in social-ecological landscapes, may offer an opportunity to explore and integrate the concepts of social-ecological innovation, resilience thinking and GI within the context of urban environmental planning.

USEI and Natural Capital

The relevance of the concept of natural capital in the context of environmental management has emerged in tandem with that of ecosystem services (Costanza and Daly, 1992; Costanza et al., 1997; Pearce, 1998; Costanza, 2000). Conceptually, the two are closely aligned whereby natural capital is described as the planet's "stock" of natural assets from which flow the ecosystem services vital to human well-being (European Commision, 2011). Both terms have been employed extensively in efforts to value the natural environment towards the inclusion of the latter in market-based decision-making which invariably drive policy and development (Farley, 2008; Daily et al., 2009; Kallis et al., 2013; Costanza et al., 2014; Guerry et al., 2015). The natural capital approach has recently gained traction in governmental policy initiatives across Europe (European Commission, 2011; European Commission, 2013). For example, in the UK, the formation of the Natural Capital Committee, as the principal advisory body to the government on environmental policy, has placed the concept at the forefront of environmental decision making (Defra, 2015). Increasingly, therefore, and despite unabated criticism of a monetised approach to environmental accounting (McCauley, 2006, Sagoff, 2011; Knights et al., 2013), the economic implications of innovation which purport to enhance or safeguard ecosystem service provision must be considered alongside the social and ecological.

An acknowledgement and integration of key theoretical, practical and economic factors which influence current management approaches in social-ecological systems is, therefore, required in order to evaluate and facilitate innovation of a social-ecological nature. Particularly in urban social-ecological systems, which represent the most complex people-nature relationships, for communities and ecosystems to be managed sustainably, the inter-connectedness of social-ecological conditions, resilience and ecosystem service provision should inform environmental decisions. Recent work has been carried out which bridges gaps in the respective literature on GI, resilience and natural capital agendas. For example, Ahern (2011) and Ahern et al. (2014) have brought to bear a green infrastructure approach on the resilience of cities by examining the application of GI through the lens of resilience thinking. Likewise Andersson et al. (2014) used the framework of green infrastructure to demonstrate how re-connecting urban communities with their environment is a crucial aspect of effective stewardship of ecosystem services. Schultz et al. (2015) promoted the role of adaptive governance in social-ecological systems by exemplifying its effectiveness in the management of natural capital. This builds on assertions by others that sustainability, as a failed concept, ought to give way to a resilience approach to protecting vital natural capital (Benson and Craig, 2014). Although such work exemplifies the need to understand how natural capital, green infrastructure and resilience contribute to the well-being of urban residents, a framework for their integration, hitherto lacking, is necessary in order to map, evaluate and facilitate the value of innovation in urban social-ecological systems. Furthermore, although the self-organising and spontaneous nature of such innovations may be theoretically synergistic with notions of adaptive capacity, where productivity and land management have been measured empirically for examples of USEI, great variety has been observed. For example, user participation in collectively managed greening projects is highly variable: a function of site design and access (Dennis and James, 2016a). Similar studies have demonstrated that productivity in terms of ecosystem services likewise varies between examples of USEI with different management goals. For example, USEI characterised by social, agricultural or environmental aims are subject to subsequent trade-offs related to respective management emphases on leisure, horticulture or biodiversity outcomes (Dennis and James, 2017a). Therefore, although collective action appears to be the central organising innovation associated with such activities, USEI has not yet been properly conceptualised as a functioning component of urban landscapes. Such an evaluation is needed in order to understand which factors influence organisation, participation and productivity at the site-level as well as resilience across scales. Here we propose such a framework, highlighting the connections between social-ecological conditions, innovation, and resilience of ecosystem services. The framework focuses in particular on the contribution of urban social-ecological innovation to desirable feedbacks which influence the resilient delivery of ecosystem services. The focus here is on self-organising, community-led practices and, as such, wider issues relating to environmental governance, which have been described elsewhere (e.g. Ernston et al., 2008), are not explicitly considered. Rather, social and governmental institutions are acknowledged as wider constraining influences on the emergence of social-ecological innovation. Notwithstanding these constraints, we argue that the basic characteristics of self-organisation and ecosystem services stewardship are common to USEI as demonstrated by evidence from the related literature.

In the sections of this paper that follow we firstly describe the components of social-ecological systems and how these combine to influence the resilient delivery of ecosystem services. We then illustrate the attributes of social-ecological innovation and, drawing on recommendations from the scientific literature, identify criteria for evaluating the potential of USEI to contribute to resilience. Finally, an instance of urban social-ecological innovation, in the well-documented form of collectively-managed urban gardens, is given as an example of how USEI can be validated according to these criteria. In so doing we demonstrate the anatomy of USEI and how the framework can be used to evaluate the potential contribution of social-ecological innovations to urban well-being. By presenting a worked example of how the central topic of this conceptual framework can be traced and understood, through its application to a “real-world” example, we demonstrate how such a framework can be operationalized. Given the absence of sufficient testing of previous frameworks published within the social-ecological literature (e.g. Pickett et al., 1997; Rennings, 2000; Tzoulas et al., 2007; Hansen and Pauleit, 2014), the work presented here, therefore, marks a considerable advance in the understanding and demonstration of social-ecological dynamics through a framework approach.

Towards a framework for evaluating innovation in urban social-ecological systems

A framework depicting the cyclical relationship between social-ecological conditions, resilience and ecosystem services in human-modified systems is presented in Figure 1. In essence, these aspects are co-dependent and the flow of energy has the potential to generate positive feedback loops. Existing social-ecological conditions provide the context for elements which influence system resilience. Principally, and generally speaking, such conditions are the result of co-existing levels of both natural and human capital. Here we employ the latter term to include not only the strength and extent of social networks (i.e. social capital) but, in addition, other factors that shape both quality of life and a relationship with the natural world for urban residents. For example, social determinants such as education, ecological and cultural heritage, community cohesion as well as socio-economic conditions can all influence human well-being and connection with the natural environment (Krasny and Tidball, 2009; Tengberg et al., 2012; Smith et al., 2013; Wu, 2014) in urban areas. Examples of natural and human capital which contribute to urban social-ecological conditions include social-ecological memory (Andersson and Barthel, 2016) and learning (Dennis and James, 2017a), biological, organisational and cultural diversity (Folke et al., 2003; Armitage, 2005; Barthel et al., 2013; Leslie and McCabe, 2013), amount and quality of urban green space (Tzoulas et al., 2007; Panagopoulos et al., 2016; Dennis and James, 2017b) and social networks and cohesion (Adger, 2003; Delhey and Dragolov, 2016). The presence of such factors can promote system resilience in the face of disturbance and the continued production of vital ecosystem services (Biggs et al., 2012). The latter in turn support healthy social-ecological conditions, elements of which may feedback directly into the generation of benefits to human well-being in the form of fast variables, such as stakeholder-led agriculture (Barthel et al., 2010), user participation (Dennis and James, 2016a) and increased physical activity (Wood et al., 2016). In this way, baseline social-ecological conditions represent a pivotal aspect and comprise simultaneously the primary cause and effect in the cycle. Combinations of natural and human capital generate a range of ecosystem services which directly influence human well-being and promote functional diversity and redundancy. The extent to which these factors are enhanced has a direct impact on a society's ability to manage for resilient social-ecological systems in the long-term (Holling, 2001), upon which the continued supply of services to human well-being depends.

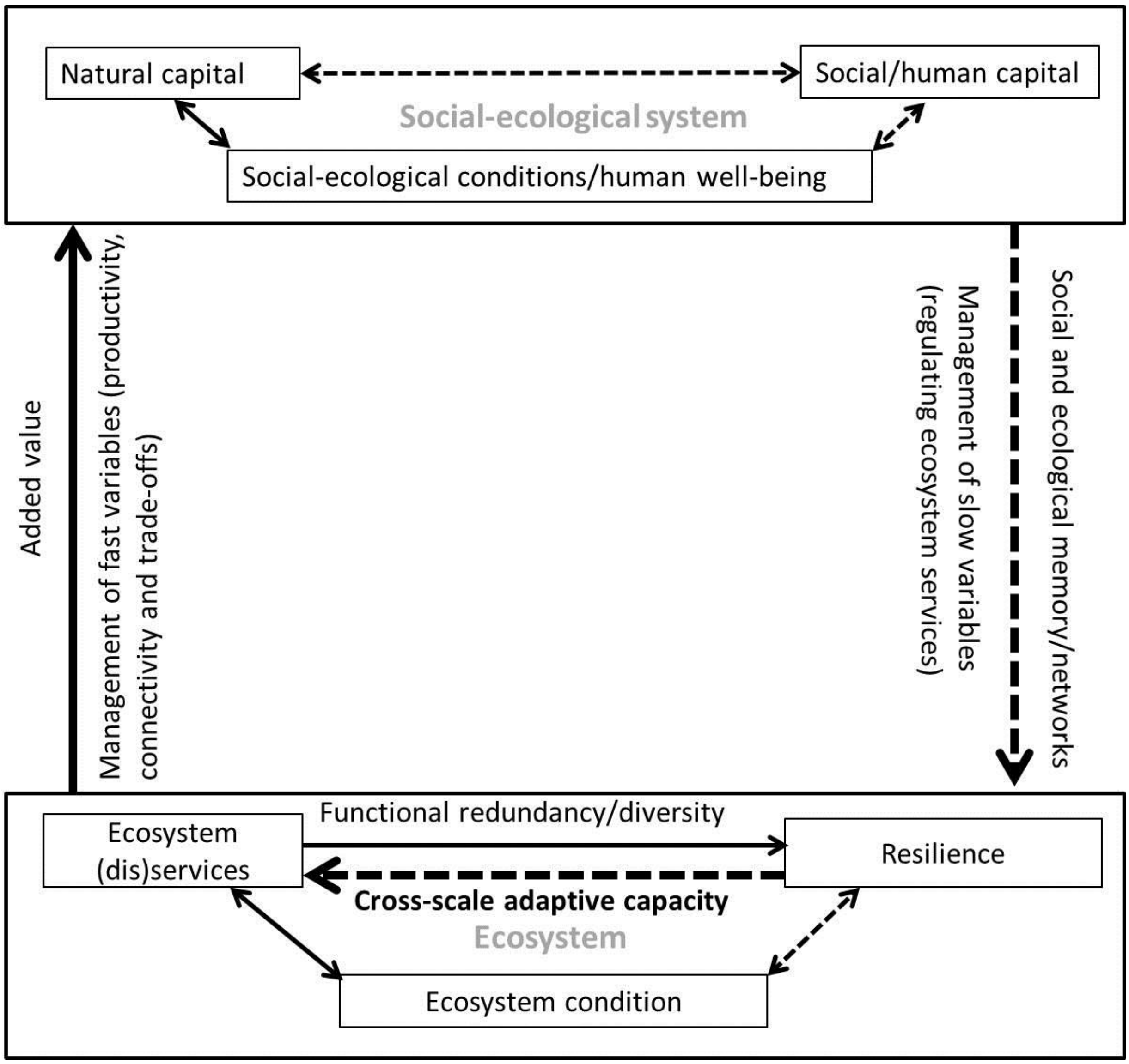

Figure 1 Interconnectedness of social-ecological conditions, resilience and ecosystem services in sustainable social-ecological systems. Full and dashed lines represent fast and slow processes respectively. *Fast* and *slow* processes are indicated by full and dashed lines respectively.

The framework in Figure 1 facilitates modelling desirable as well as undesirable positive feedbacks. The latter consist of cyclical trends which may develop from poorer pre-existing background conditions where social and natural capital are lacking and the ability to adapt is slow. Undesirable positive feedbacks are characterised by the presence of traps in the adaptive cycle (Carpenter and Brock, 2008). *Rigidity traps* result from highly connected systems with low functional and, therefore, response diversity. This in turn inhibits adaptability in the face of external or internal change and the effective management of slow variables. If thresholds determined by slow variables (such as land-cover change, soil formation, carbon sequestration) are exceeded which determine the responsivity of fast variables (in the form of goods and services e.g. food production) to environmental conditions (Walker and Salt, 2012), then system regime shifts can occur, threatening the provision of vital ecosystem services. Moreover, lack of human capital may subsequently create *poverty traps* where pre-existing conditions do not allow the necessary innovation required for re-organisation and exploitation of resources following regime change (Biggs et al., 2012). A pertinent example of the latter in the context of USEI relates to the critical role that leadership plays in the emergence and continuation of innovative practices. Often the creation and sustainability of community-led common-pool resource management practices in urban areas is highly influenced by the presence of gatekeepers. This latter term describes individuals or organisations that exert high degrees of influence within actor networks as a result of social position, mobility or leadership. Both poverty and rigidity traps may emerge as a result of the influence of such actors. For example, the absence of sufficient leadership and mobility of key community members may be a barrier to the ability of groups to self-organise and develop innovative programs of work (poverty trap). Conversely, if the high influence exerted by gatekeepers is directed towards the exclusion of certain individuals or groups from participation or a narrow approach to management, rigidity traps can occur through the associated reduction in diversity and management options (Ghose and Pettygrove, 2014). Traps can also occur as the result of wider social-ecological contexts. For example, high levels of ecological deprivation in the form of limited access to green space can remove the opportunity for innovation as can severe levels of social deprivation which reduce social ties and the capacity for communities to self-organise (Walker et al., 2006). Similarly, inflexible common property institutions represent rigidity traps which may reduce access to local resources by community groups (Folke et al., 2009). A key consideration, therefore, in the potential for USEI to contribute to the resilience of ecosystem services stems from its ability to foster participation and adaptation, where challenging social-ecological conditions present opportunities for change, but of equal importance is an acknowledgement of its inherent susceptibility to impedance by traps.

Given these traits of social-ecological systems we propose that, in order to understand the potential of USEI to contribute to long-term resilience of ecosystem services, it must be assessed against the related criteria:

Criterion i) the ability to respond to environmental conditions,
Criterion ii) productivity in terms of ecosystem services (fast variables),
Criterion iii) management of regulating ecosystem services and slow variables, and
Criterion iv) promotion of functional diversity and redundancy

These criteria are visualized in Figure 2.

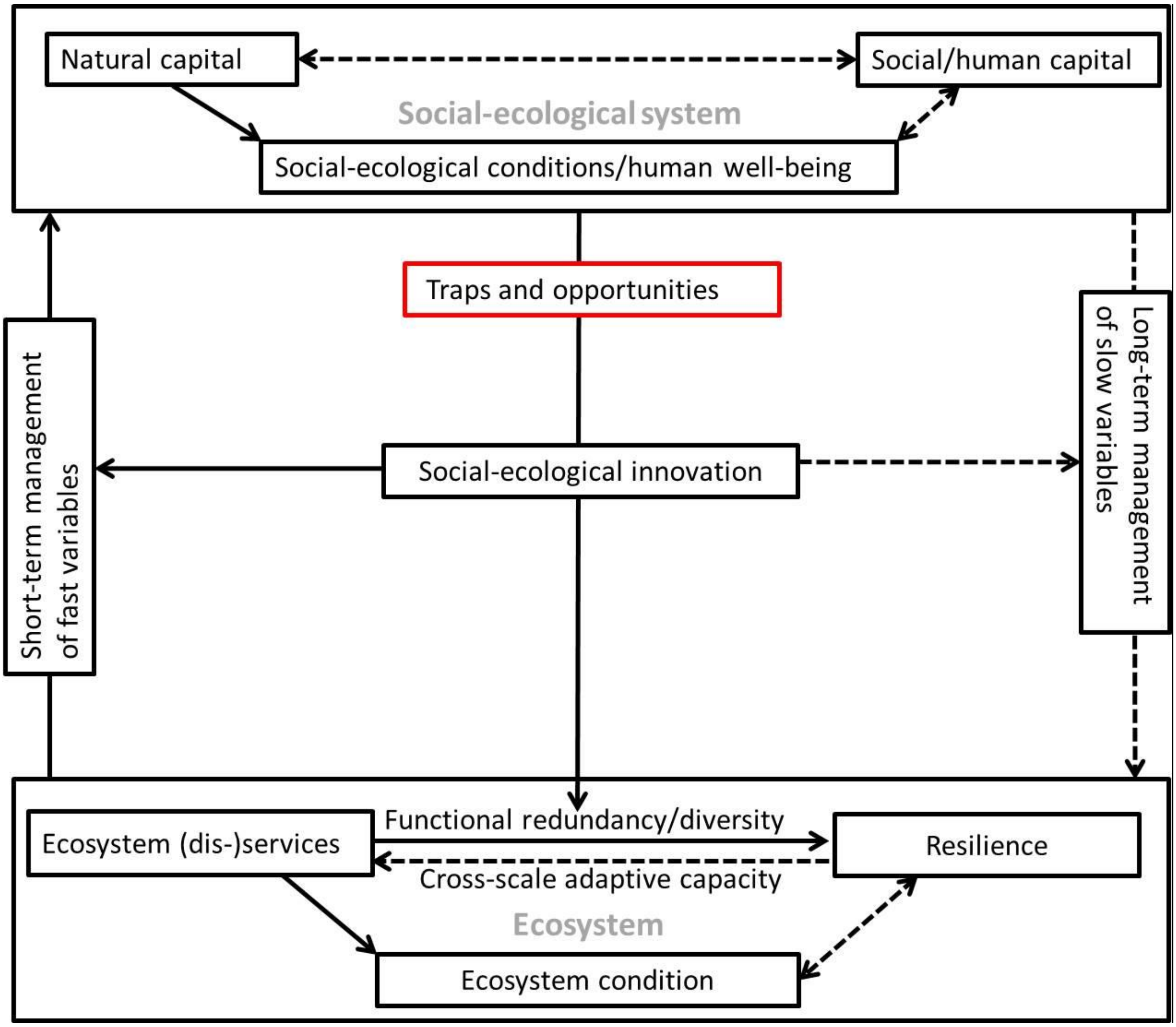

Figure 2 How social-ecological innovation may contribute to the resilience of ecosystem services. Here, social-ecological innovation occurs as a response to social-ecological conditions where opportunity for innovation exists and where traps are either absent or overcome by sufficient combination of human and natural capital (Criterion i). The ability to support vital ecosystem services as direct benefits represents the contribution of social-ecological innovation to the management of fast variables (Criterion ii) and its influence on larger-scale constraining processes characterises the potential for long-term management of slow variables: Criterion iii). The extent to which social-ecological innovation promotes functional diversity and redundancy directly influences the capacity of ecosystems to maintain critical functions and services in the face internal and external disturbances (Criterion iv). *Fast* and *slow* processes are indicated by full and dashed lines respectively.

The potential of collectively-managed urban gardens as a social-ecological innovation towards building resilience in the urban landscape

Collectively-managed urban gardens (CMUGs; Dennis and James, 2017a) represent an instance of urban social-ecological innovation that has received significant attention in research on ecosystem services (Bendt et al., 2013; Camps-Calvet, 2016; Dennis and James, 2016a; 2016b; Cabral et al., 2017), civic ecology (Krasny and Tidball, 2015), social-ecological systems (Barthel et al., 2010; 2013) and urban planning (Hardman and Larkham, 2014). They are characterised by bottom-up community-led horticulture and as such meet the definition of USEI, as self-organising, emergent phenomenon, employed here. Examples include community-managed allotments (Colding and Barthel, 2013), gardens (Pourias et al., 2015) and orchards (Travaline and

Hunold, 2010) as well as less traditional, highly improvised spaces such as green roofs and walls, and pocket parks (Dennis et al., 2016a). Research on CMUGs has focused on benefits related to knowledge exchange (Ernstson et al., 2008; Barthel et al., 2014), participatory approaches to environmental stewardship (Ernstson et al., 2010; Andersson et al., 2014; Middle et al., 2014), and local adaptive responses to social-ecological stressors (Dennis and James, 2016a; 2016b). As such, the evidence-base on benefits and challenges related to CMUGs is sufficient to provide a promising medium through which to explore the role of USEI in the resilience of ecosystem services, and, the efficacy of a framework to map such capacity. We do so according to the four criteria for evaluating USEI set out in the previous section.

Criterion i) Response to environmental conditions

Work by Dennis et al. (2016a) and Dennis and James (2016b) has provided insight into community-led, social-ecological innovation as a phenomenon which is significantly shaped by spatial characteristics in terms of its distribution and expression. The emergence and distribution of social-ecological innovation in the urban landscape represents a diverse social-ecological response to low quality urban environmental conditions. Dennis et al. (2016a) found that the occurrence of CMUGs was responsive to both social and ecological patterns of deprivation in the landscape of Greater Manchester, UK, highlighting their ability to adapt in the face of untenable social-ecological conditions. Moreover, the occurrence of CMUGs was found to be influenced by both physical features of the environment as well specific socio-economic conditions such as crime and health deprivation (Dennis et al., 2016b). These factors were shown to closely shape the form that discrete *types* of CMUGs take (e.g. gardens, orchards and pocket parks), demonstrating that such innovations respond to particular social-ecological niches. CMUGs, therefore, represent an adaptive form of resource governance according to local conditions and, as such, meet the requirements of a system ingredient which builds on resilience (Elmqvist et al., 2003; Folke et al., 2005; Walker et al., 2006; Gunderson, 2010; Barthel et al., 2013).

However, USEI is a phenomenon embedded in the adaptive cycle of complex adaptive systems and is accordingly subject to the thresholds and traps which define such cycles (Carpenter and Brock, 2008; Dennis et al., 2016b). Although responsive to social and ecological levels of deprivation, USEI is subject to threshold effects whereby its occurrence is influenced in a non-linear fashion by combinations of environmental stressors. This effect was highlighted in Dennis et al. (2016b) in which thresholds described by very low or very high levels of, particularly socio-economic, deprivation were identified outside of which the emergence of CMUGs was inhibited. Therefore, the presence of certain levels of human capital appears to be pivotal in the self-organisation of local communities. Research in Philadelphia, for example, has highlighted how communities with low social or political capital are much less likely to succeed in the establishment of collectively-managed local green assets (Meenar and Hoover, 2012). Social-ecological innovation, as a landscape phenomenon, is accordingly subject to the stages, transitions and traps of the adaptive cycle. However, where CMUGs do emerge they do so by exhibiting key attributes necessary for system resilience, namely: capacity for self(re)-organisation (transformability) and response diversity (adaptability) (Folke et al., 2005; Walker et al., 2006). Specifically, self-organisation is permitted by social capital and education (Dennis et al., 2016b), response diversity is exhibited through adaptation to environmental conditions (Dennis et al., 2016a). Furthermore, evidence suggests that CMUGs can also support the protection of vital urban ecosystem services (resilience) through user participation in the management of urban commons (Barthel et al. 2010; Dennis and James, 2016b).

Criterion ii) Ecosystem services: productivity and trade-offs and Criterion iii) managing slow and fast variables

A common feature of CMUGs is a characteristic emphasis on communal green space restoration taking food production as a medium for social-ecological activism (Barthel et al., 2010; Dennis et al., 2016b). In this respect, urban agriculture appears to be an effective medium for a variety of types of social-ecological innovation (Barthel et al., 2010; 2013; Hardman and Larkham, 2014; Dennis and James, 2016b). Not only does urban agriculture appear to facilitate the emergence of social-ecological innovation (Krasny and Tidball, 2015; Dennis et al., 2016b) but subsequently, it has also been shown to have a significant synergising effect on the production of a range of ecosystem services (Dennis and James, 2016b).

Design characteristics also appear to be influential in the capacity of CMUGs to effectively deliver social and ecological benefits, characterised by an observed inverse site-size productivity relationship (Dennis and James, 2016b; 2017b). The latter describes an observed phenomenon in ecosystem service provision whereby a negative linear relationship exists between increasing site size and productivity per unit area. This can result in the occurrence of highly productive multifunctional micro-scapes (Dennis and James, 2016c). Moreover, given the high surface sealing and low ecological quality of the spaces in which such sites often occur (Krasny and Tidball, 2015; Dennis et al., 2016a), their impact can be particularly transformative. One of the strengths of CMUGs is related to the positive social-ecological feedbacks inherent in the productivity of these spaces. Community involvement (in, for example, food cultivation) simultaneously constitutes a key input (as a resource for ecosystem management) as well as generating various outputs such as food provisioning (Lawson, 2005), habitat management (Natural England, 2014; Krasny and Tidball, 2015) and benefits associated with participant physical activity (Hynes and Howe, 2004; Dennis and James, 2016c). Further to this, user participation has been shown to correlate positively with overall productivity in ecosystem services (Dennis and James, 2016b). In this way the dynamics of social-ecological innovation describe beneficial positive feedbacks with the potential for efficient closed-loop systems of goods and services. Due to the productivity of, and user participation at, CMUGs there is also great potential value in the associated generation of ecosystem goods and services. For example, Dennis and James (2016c) recently found existing transferable valuation data for urban green space to be highly generalised and failed to honour the variety and multi-functionality of collectively managed spaces. Providing a more detailed assessment of pockets of urban green space, taking into account user participation, their study highlighted the added-value brought about by such involvement as being considerably greater than an internationally recognised baseline (TEEB database: Van der Ploeg and De Groot, 2010).

Not only does this suggest that CMUGs are highly productive in terms of direct use benefits, but user participation at CMUGs also contributes to the generation of vital slow variables relevant to urban environments. For example, regulating ecosystem services such as habitat for pollinators and water attenuation are possible through community-led restoration of urban habitats (Tidball and Krasny, 2010). In addition, reduction of food-related carbon emissions (Kulak et al., 2013) and improved soil quality and carbon storage (Edmondson et al., 2014; Beniston and Mercer, 2015) have been evidenced though urban agricultural practices. Furthermore, the latter has been put forward as a source of local ecological knowledge (Bendt et al., 2013; Andersson et al., 2016) and social capital (Ernstson et al., 2010) which can broaden long-term environmental management options (Olsson al., 20005; Barthel et al., 2010). Given that community-led agriculture is often committed to organic, permaculture-based horticultural methods and closed-loop systems of food cultivation (Stocker et al., 1998; Holland, 2004; King, 2008), CMUGs may also bring benefits associated with slower ecological processes such as biological control, increased soil microbial biomass and biodiversity gains (Maeder et al., 2002; Tscharntke et al., 2005; Kramer et al., 2006; Sandhu et al., 2010).

Notwithstanding the benefits associated with multi-functionality at CMUGs, an assessment of the former is not complete without due consideration of trade-offs resulting from the latter. Tensions have been identified between levels of site use and micro-climatic benefits at CMUGs, a trade-off seemingly related to site size and levels of surface sealing (Dennis and James, 2017a). For example, relatively lower participation at larger sites of social-ecological innovation, due to their size, access and location (Dennis and James 2016a; 2016b), may result in such sites being less effective as social interventions. However, from a resilience perspective, although larger sites may be less productive per unit area in terms of ecosystem services, they may provide valuable functional diversity, and redundancy. By virtue of their less intensive management (Dennis and James, 2016a), larger, more naturalistic sites may preserve important slow variables in the landscape such as ecological succession and habitat for wildlife (Alvey, 2006), and water regulating processes (Jim and Chen, 2009). Such trade-offs related to design (in particular site size and cover) and management (e.g. for food, habitat or recreation) must be weighed up if innovations such as CMUGs are to be successfully integrated into planning frameworks.

Criterion iv) Diversity and redundancy

In terms of biological diversity, the possibility of reconciling the historically destructive nature of the human-environment relationship in urban areas has been given support by findings that indicate a positive correlation between levels of civic-ecological participation and increasing biodiversity potential in pockets of urban green space (Speak et al., 2015; Dennis and James, 2016a; Borysiak et al. 2017; Cabral et al., 2017). Ecological restoration achieved by CMUGs not only appears to bring about genera rich and structurally diverse pockets in the landscape (Dennis and James, 2016a), but its distribution is such that it generally serves the most urbanised locations (Dennis et al., 2016a). Research in urban ecology has highlighted the value of urban domestic gardens which enhance locally important ecological networks and, therefore, make significant contributions to urban biodiversity conservation (Smith et al., 2006; Davies et al., 2009; Goddard et al., 2010; Goddard et al., 2013). For example, urban domestic gardens and allotments (Speak et al., 2015) contribute to spatial heterogeneity and provide habitat for pollinator groups. This may promote important functional redundancy (Osborne et al., 2008; Samnegard et al., 2011) given that surrounding agricultural areas can often perform less well in supporting such functional groups (Matteson and Langellotto, 2009). The potential contribution of CMUGs to spatial connectivity in the physical landscape carries with it also the broadening and strengthening of social-ecological networks (Crowe et al., 2016). If acknowledged by agencies at higher levels of governance, such networks could contribute to the resilience of urban natural resource management (Ernstson et al., 2010) by increasing management options through functional diversity and redundancy (Colding and Barthel, 2013).

The role of urban social-ecological innovation in complex adaptive urban social-ecological systems

CMUGs, presented here as an example of urban social-ecological innovation, have the potential to fulfil many of the requirements which contribute to a resilience approach to ecosystem services management (i.e. criteria i) to iv)). The collective management of open spaces by self-organising end users contributes to a diverse bank of management options for urban green commons and builds on environmental (Krasny et al., 2014) and social learning (Bendt et al., 2013). Through the cultivation of food in particular, horticulture-oriented innovation acts as a medium for education and, accordingly, a retainer of social-ecological memory (Barthel et al., 2014). Given that social-ecological innovation has the potential to increase productivity, in terms of ecosystem services, of under-used and/or poor quality green space (Krasny and Tidball, 2015; Dennis and James, 2016b), it also creates opportunities for desirable positive social-ecological feedbacks. The conceptual framework outlined in Figure 2 can be used to map these feedback loops and account for the qualities of CMUGs which relate to social-ecological conditions, ecosystem services and resilience (Figure 3). This framework could be adapted for any social-ecological innovation by replacing CMUGs with other forms of USEI and modifying the links to ecosystem services, fast and slow processes, diversity and resilience as appropriate.

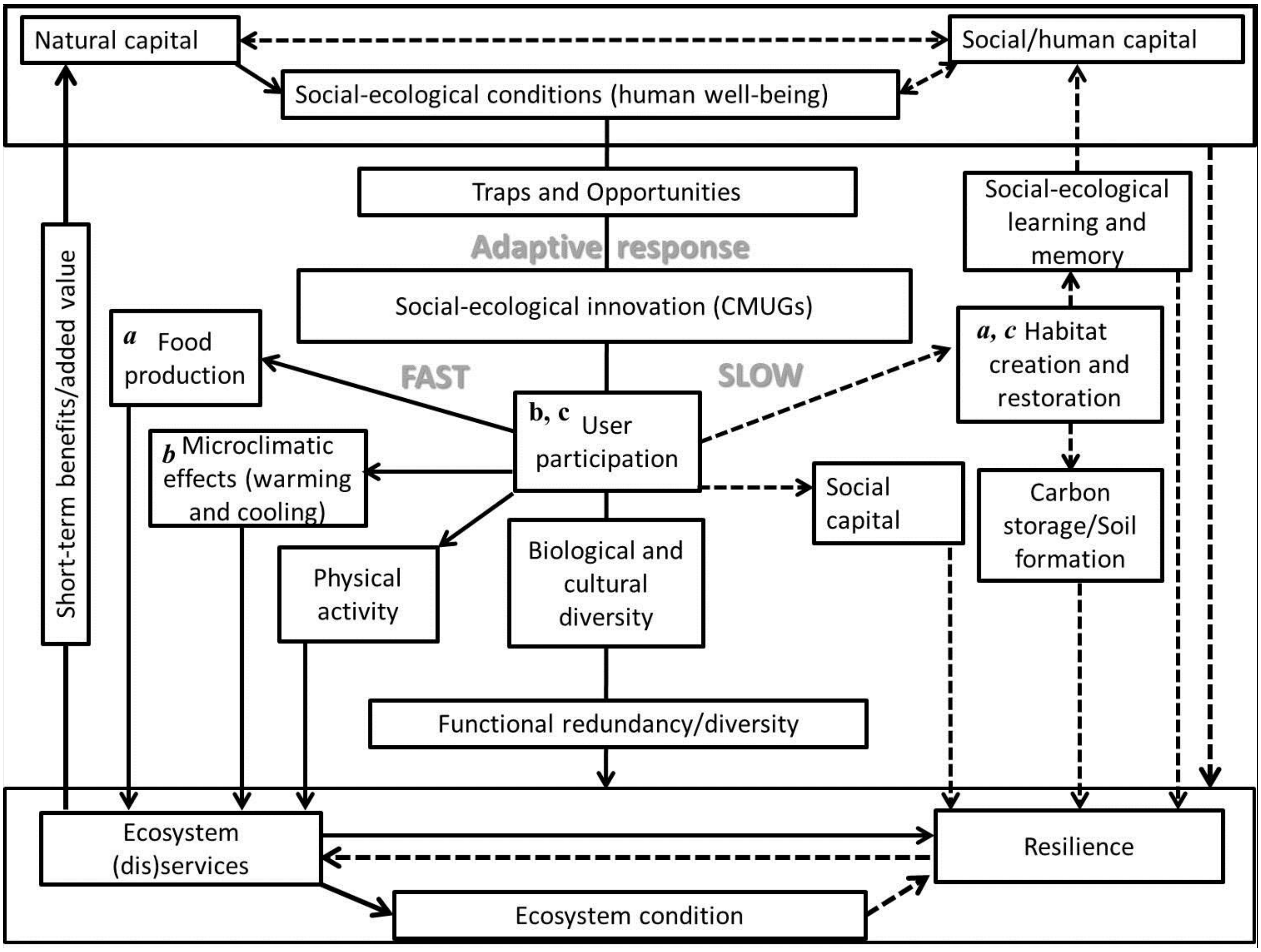

Fig. 3 Conceptual model describing social-ecological innovation-related feedbacks in sustainable urban social-ecological systems. *Fast* and *slow* processes are indicated by full and dashed lines respectively. Shared letters denote potential trade-offs related to site design characteristics.

Discussion

The characteristics of CMUGs that allow it to fulfil the criteria for adaptive urban social-ecological innovation are summarised in Figure 3. As an adaptive response to existing conditions, CMUGs represent a mediating element within the system, fulfilling criteria i). The validity of such a response is confirmed by the resulting positive correlations, primarily through community participation in urban horticultural practices, with vital ecosystem services (Criterion ii). These include food production (Saldivar and Krasny, 2004; Lawson, 2005), increased biodiversity and pollination potential (Colding et al., 2009; Speak et al., 2015; Dennis and James, 2016b), habitat creation and restoration (Krasny et al., 2014), micro-climate regulation (Dennis and James, 2016a), carbon sequestration (Edmonson et al., 2014), physical recreation (Hynes and Howe, 2014), soil formation (Beniston and Mercer, 2015) and nutrient cycling (McClintock, 2010).

Of these, micro-climate regulation, food production and opportunity for physical activity represent fast variables that provide direct benefits to users of CMUGs and contribute to local natural capital and ecosystem conditions (left-hand side of Figure 3). These fast variables, therefore, describe beneficial positive feedbacks between social-ecological conditions, user participation and ecosystem services.

In terms of management of slow variables (right-hand side of Fig. 3), user participation plays a key role in wider more gradual feedback processes. Resilience is directly influenced by the management of slow variables (Criterion iii) such as the promotion of local ecological knowledge, habitat restoration, soil formation and carbon storage which stem from the horticultural use of urban commons. Building local ecological knowledge is critical to resilience as it increases management options in time of crisis and promotes effective ecosystem management in the short-term (Barthel et al., 2010). Social capital is, likewise, increased through participation which enhances the self-organising abilities of communities and, therefore, their capacity to adapt to change and (re-) exploit conditions and resources. Such forms of capital, therefore, feed directly into the resilience of the system. Management (user participation) of CMUGs also builds on ecosystem-related slow variables such as soil management, where such practices are associated with enhanced organic carbon concentrations, and habitat creation and restoration. Such practices contribute to ecological resilience by, for example, improving soil health and habitat connectivity in the landscape and build social-ecological resilience through the exchange of vital ecological knowledge through participation in ecosystem management (Colding et al., 2006; Ernstson et al., 2008).

Benefits derived from the management of fast variables may provide important functional redundancy in resource-scarce urban landscapes where more traditional forms of green space are under threat (Barthel and Isendhal, 2013; Barthel et al., 2013; Andersson et al., 2014). Moreover participation is a driver of biological (Dennis and James, 2016a) and cultural (Barthel et al., 2013) diversity, representing vital insurance value and adaptive capacity in the face of social-ecological disturbances. The presence of potential feedback loops is also considered as an important tension implied in ecosystem management which may result in certain benefits being maximised over others. For example, although user participation represents a central defining and synergistic element of USEI, high levels of participation may require the development of built infrastructure (e.g. paths, seating, shelters, toilet facilities, storage) which them become an obstacle to habitat creation and restoration and effective micro-climate regulation. Likewise, intensive agricultural activity, targeting particular crops, may reduce the overall heterogeneity and naturalistic nature of CMUGs. These trade-offs are acknowledge by the assigning of common letters in the version of the conceptual framework presented in Fig. 3 and should be modified according to particular benefits associated with individual cases of USEI.

Potential applications of the conceptual framework

The conceptual framework presented here (Figure 2) represents a key contribution to knowledge on how the relationships between urban social-ecological conditions, ecosystem services and factors which affect overall system resilience interact and are influenced by social-ecological innovation. The framework provided in Figure 2 could allow agencies at all levels of environmental governance to consider how background conditions promote or impede innovative practices and how the former are affected by fast and slow process resulting from the latter. For example, such a framework could assist urban planning authorities in accounting for local USEI-related activities and their contribution to the provision of ecosystem services (fast variables) and social-ecological resilience (slow variables) of local communities, thereby allowing their integration in the GI decision-making process. Furthermore, by the same logic, the identification of benefits, trade-offs and the long-term influence on resilience associated with USEI could facilitate the visibility of the latter in local to regional natural capital accounting which, to date, does not accurately incorporate such practices despite the great levels of added-value that they can generate (Dennis and James, 2016c). If the principles of resilience and adaptation are to become central to urban environmental management then an understanding and integration of potentially resilience-enhancing practices such as USEI should be sought. The application of the framework presented here provides a means to achieve such integration.

Limitations of the work

The conceptual framework provided in Figure 2 represents the fundamental components for mapping the contribution of USEI to resilience in social-ecological systems and the example of CMUGs exemplifies the application of this conceptual framework to model desirable positive feedbacks generated by the occurrence of innovation in response to social-ecological conditions. However, the relationships described in Figure 3 assume the nature of USEI as an adaptive response and, although the importance of traps and opportunities is underlined, the combinations of social-ecological conditions upon which they depend are not considered in detail other than their characterization as being dependent on levels of social and natural capital. Therefore, the application of the conceptual framework requires a context-specific framing where challenges and opportunities related to governance, socio-cultural factors and natural capital are known in advance. Such knowledge can thereby be applied to anticipate both the potential obstacles to self-organization and participation within local communities as well the direct and indirect benefits which may result from such participation. In particular the role of wider governance and scale-crossing brokers may themselves represent "slow variables" which constrain the emergence of innovation (Ernstson et al., 2008). Again, although we allude to the importance of such factors in our framework, the complexity and context-specific nature of local, regional and national environmental governance systems should be taken into account on a case-by-case basis when assessing the potential traps and opportunities related to USEI. With this in mind, one possible future development of the framework outlined is the integration of those insights mapped here with those described elsewhere on aspects of wider governance and social institutions (e.g. Ernstson et al. 2008 or Ostrom, 2009) which may mediate the level of opportunity for innovation and subsequent integration into urban environmental planning. Further development of the ideas presented here are indeed necessary in order to begin to appreciate the implications of attempts to integrate the activities of self-organising environmental actor networks into traditional hierarchical models of urban planning.

Conclusions

The urban landscape can be seen as a rich context for studying the dynamics of social-ecological systems and their associated resilience traits as well as a valuable source of innovative ideas, networks and practices which stand to inform the adaptive management of human and ecological capital. The framework described here includes those components that provide a conceptual basis with which to unpick potential benefits, limitations and trade-offs arising from the emergence of self-organising social-ecological actors. By focussing on a well-researched example of USEI, a better appreciation of how social-ecological innovation may influence the resilience of vital urban ecosystem services has been exemplified. The work, therefore, provides an example of how conceptual models related to vital elements of social-ecological systems can be conceived and validated through the application of evidence-based criteria, supported by the broad contributions to this field of study in recent years.

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