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Toward a typology for social-ecological systems

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Characterizing and understanding social-ecological systems (SESs) is increasingly necessary to answer questions about the development of sustainable human settlements. To date, much of the literature on SES analysis has focused on “neat” systems involving a single type of resource, a group of users, and a governance system. While these studies provide valuable and specific insights, they are of limited use for application to “messy” SESs that encompass the totality of human settlements, including social organization and technologies that result in the movement of materials, energy, water, and people. These considerations, in turn, create distribution systems that lead to different types of SESs. In messy SESs the concept of resilience, or the ability of a system to withstand perturbation while maintaining function, is further evolved to posit that different settlements will require different approaches to foster resilience. This article introduces a typology for refining SESs to improve short- and long-term adaptive strategies in developing human settlements.

KEYWORDS: vulnerability, human settlements, social organization, resource management, local communities

Introduction

Over the past twenty years, a growing community of practice has treated human and biophysical systems as linked and has characterized them as constituting social-ecological systems (SESs), that is as complex, integrated systems of humans within the ecosystem (Berkes & Folke, 1998; Holling 2001; Colding et al. 2003; Anderies et al. 2004; Forbes et al. 2004; Adger et al. 2005; Young et al. 2006; Smith & Stirling, 2008; Walker & Lawson, 2009). An SES is comprised of feedbacks among human values, perceptions, and behaviors and the biophysical components of the ecosystems in which people live, resulting in a “resilient” or “vulnerable” trajectory trending toward sustainability or collapse (Gallopin, 2006). However, when technology is factored in, these feedbacks result in markedly different outcomes depending on the type of SES.

A growing body of literature (e.g., Ostrom, 2007; Resilience Alliance, 2007a; 2007b) examines the management of SESs, but treats them as “neat” systems in which humans and their resources are reduced to “blocks” representing subsystems with simple and relatively clear flows (Anderies et al. 2007). Neat SESs in this context deal with a well-defined (often single) resource, a group of users of this specific resource, and a set of common-pool resource governance systems. This emphasis on neat SESs makes it difficult to accommodate an associated sociotechnical regime (Smith et al. 2005) and often leads to recommendations that are difficult for the majority of sustainability practitioners to translate. We argue for the need to move away from the idealized concept of “neat” SESs and to develop the concept of “messy” SESs involving the simultaneous use of multiple resources by diverse users and the technologies they employ. Such a viewpoint can more readily accommodate the inherent complexity of SESs than strictly neat SESs. For example, an SES comprising a village in northwestern Alaska and the subarctic tundra landscape in which it exists (e.g., Alessa et al. 2008) is subject to the seasonal and cyclic availability of subsistence species (e.g., salmon, caribou, moose, walrus, seal), the consequences of regional, national, and global economies, and global climate-change effects on precipitation and temperature—to name just a few of the SES dynamics at play in this particular case.

The Need for a Typology of Messy SESs

As a first step in the challenging task of moving toward messy SESs, we propose that different messy SESs can be distinguished into ideal types that reflect combinations of the inherent robustness of natural resources (i.e., water, food, and materials), social organization (including policies), and infrastructure/technology that contribute to efficiency (e.g., transportation). Diverse disciplines use typologies (Winch, 1947; McCullough, 2001; Morillo et al. 2003) and this article adopts this methodology to move from an abstract concept to a practical application. The proposed classification is a continuum along which human settlements can be typed rather than a strict taxonomy with clear and well-defined boundaries. We believe this approach will help to develop strategies that better promote adaptation to change in diverse settings. The types presented here are intended to be neither exhaustive nor prescriptive; rather, they are offered as a demonstration of what a typology for messy SESs might look like, acknowledging that the concept will require further development.

An Initial Framework for Messy SES

We organize our typology along a continuum of community size, reflecting ecosystem productivity, social organization, and responsiveness (or adaptability) to maintain resilience or a resilient trajectory (in which a settlement's actions will eventually lead to resilience). The three scales used accommodate differences in sociometabolic and land-use transitions (Krausmann et al. 2008; Nuissl et al. 2009) associated with a coarse differentiation between city-, town-, and village-level settlement sizes, ranging from high-density to low-density urban structures (Figure 1). The size continuum is based on the central idea that both size and scale matter and that the way an SES is viewed and managed will, in part, reflect this parameter. The second continuum is meant to capture the responsiveness of the SES to its current trajectory (Walker & Meyers, 2004): trending toward resilience, a transitional state at a threshold that could move either toward resilience or vulnerability, or a condition of vulnerability or even collapse (Figure 1). Thus, in the extremes, a large community with ineffectual social organization located in a natural resource-poor area will be the least resilient and a smaller, more effectively organized one situated in a resource-plentiful area will be the most resilient. Between these two poles are many types of settlements that will possess features that result mainly in a trajectory toward one type or the other. Understanding all types is important since we can learn why some settlements are comparatively resilient, even when resources are relatively scarce, and recognize which interventions will be more or less worthy of investment.

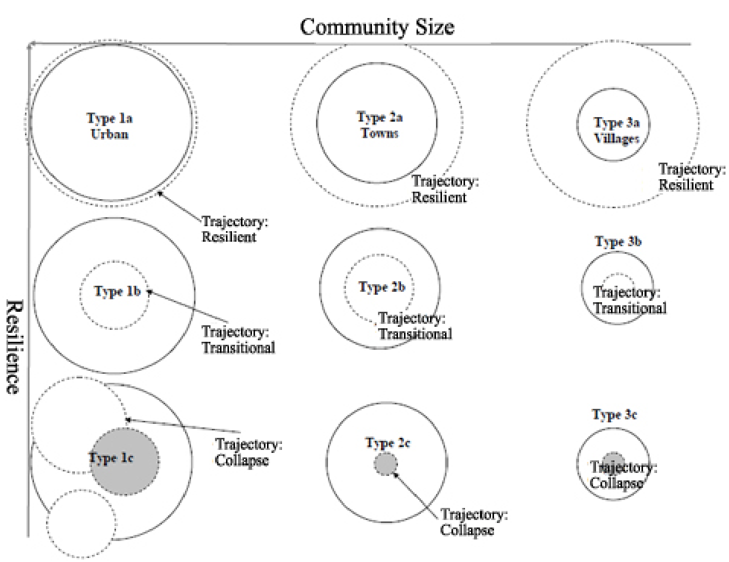

Figure 1 Framework for messy social-ecological systems.

Social-Ecological Systems

Approaches to describing and analyzing SESs include concepts of robustness (e.g., Anderies et al. 2004), resilience (e.g., Walker & Lawson, 2009; Walker & Salt, 2006), thresholds (e.g., Walker & Meyers, 2004), vulnerability (e.g., Gallopin, 2006), sustainability (Kajikawa, 2008), human settlements (United Nations-Habitat, 2007), sociometabolic transitions (e.g., Krausmann et al. 2008), sociotechnical systems (Smith & Sterling, 2008), and land-use transitions (e.g., Nuissl et al. 2009).We define a resilient SES as one that can meet its needs and desires within the means of its local environment, where "local" reflects variable scalability relative to the geography surrounding a settlement, and possesses a trajectory consistent with maintaining this condition over long time periods. While this is an idealized definition, since it is problematic that any modern city or town can be wholly resilient or even completely dependent on its local environment, it provides a basis for a relative scale of resilience in SESs, allowing the identification of cities or towns that possess greater resilience and others that possess greater vulnerability. It is also a provisional, simplified definition that is a starting point for understanding "messier" conditions.

In their simplest form, types of SESs can be organized based on the ability to acquire, distribute, and sustain access to natural resources over long intervals through tradeoffs that maintain a dynamic and flexible equilibrium between social and ecological well being (Colding et al. 2003). Additionally, the ability for settled communities to mitigate unexpected exogenous events is important in determining resilience. To define these measures, we use the notion of access to designate resources in close proximity to a community *or* for which there is sufficient means to either extract or import the resources. The ability to distribute resources implies the capability for institutions to function more or less efficiently and equitably so that needed or desired resources move to individuals and households, and for communities to regulate when a given resource is available (Anderies et al. 2007). Exogenous events in this case represent outside social-ecological occurrences over which a community has little or no direct control, but to which it can respond and mitigate undesirable outcomes. Resources, in this case, are defined as goods and services intended to enhance a community's quality of life regardless of any waste (Rogerson, 1995). This feature reflects the fact that while all societies seek to meet their needs and desires, there are several SES types in which basic human needs remain unmet and which incur the impact of distant resource supplies. The importance of understanding what type of messy SES a practitioner is assessing is critical in developing appropriate strategies that promote resilience in a timely fashion.

Sociometabolic transitions refer to the dynamics of material and energy flows in a society over long periods (Geels, 2005; Krausmann et al. 2008) and provide a mechanism for considering SESs. While broad transitions in energy flows—for example from an agrarian to an industrial society—can indicate different levels of sustainability, the trajectory of an urban center's socioeconomic metabolism, such as decreasing consumption of fossil fuel, may contribute toward resilience in a SES.

SES types have been conceptualized as the interactions between social institutions and biophysical dynamics. For example, a subset of social-biophysical interactions in SES types are ecological-economic systems that describe human activity involving the joint interaction of ecological (e.g., soil fertility) and economic (e.g., commodity prices) factors affecting commercial and agronomic facets of modern food production (Batabyal & Yoo, 2007). However, in reality many SESs at the extremes of the continuum should be considered as social-technological systems (Smith & Stirling, 2008). As an example, a city with rapidly growing squatter settlements may be in the process of building permanent subsidized housing to manage the consequences of uncontrolled human waste (i.e., disease vectors), thus moving itself toward a more resilient state, but this characterization holds true only if there are adequate water resources and treatment technologies. Conversely, a city may experience rapid immigration from rural areas with no plans or means to address the consequences of population growth, thus moving the SES toward vulnerability.

In conceptualizing the SES typology, we assimilated a diverse body of knowledge relevant to resilience and sustainability including the following:

- Inherent productivity and vulnerability to catastrophic events in ecosystems on earth (e.g., Adger et al. 2005)
- Land use and land-cover change (e.g., Lambin et al. 2003; Nuissl et al. 2009)
- Rapid changes observed under global environmental stress (e.g., Alley et al. 2003)
- Institutions and governance of natural resources (e.g., Ostrom, 2005; Armitage, 2008)
- Migration and demographic structure (e.g., Adger et al. 2002; Berkes et al. 2003)
- Cooperative and adaptive management (e.g. Carlsson & Berkes, 2005; Armitage et al. 2007)
- Perceptions and awareness of change in water resources (e.g., Alessa et al. 2007)
- Socio-technological regimes (e.g., Smith & Stirling, 2008)
- Socio-economic metabolism (e.g., Krausmann et al. 2008).

A Typology of Messy SES

The framework for the SES typology (Figure 1) is refined by incorporating diagnostic or indicator variables (Table 1) that provide an aggregate determination of the resilience trajectory for a particular SES. These variables are derived from resilience frameworks (Ostrom, 2005), resilience case studies (Walker & Lawson, 2009), socio-metabolic transition frameworks (Krausmann et al. 2008), and land use transition frameworks (Nuissl et al. 2009). Each indicator is represented as a binary value, high or low, and in the examples given (Table 2) is reached using the Delphi technique (Rowe & Wright, 1999) as a means for obtaining a reliable consensus by a panel of resilience practitioners (including biological, physical, and social scientists) using a series of questionnaires with controlled feedback. The Delphi technique is a method for structuring information derived from a group of experts and developing consensus on the best available knowledge to deal with a complex problem. Where possible, a quantitative measure for each indicator is used to provide consistency and robustness. For example, we base variability in resource availability on OECD (2007) environmental data for water demand, accessibility, and potability. Communication is a measure of the connectivity of an SES and is based on the connections and strengths of global network links that rate cities around the globe within economic and communication networks (Derudder et al. 2003). We predicate risk to an SES due to natural hazards upon the ranking of cities around the globe based on their exposure to coastal flooding, storm surge, and high wind damage (Nicholls et al. 2008).

For each scale (city, town, village), an SES is categorized as Type A (resilient) where the majority of indicators (8 of 10) are high, as Type C (vulnerable) where the majority of indicators (8 of 10) are low, and as Type B (transitional or mixed) where the indicators are neither predominantly high nor low. In addition to the overall categorization of SESs (Figure 1), the variables that each indicator describes (Table 1 and 2) provide diagnostic value for understanding messy SESs. However, we caution that this is a provisional framework and it will require significant input from a diverse community of practitioners to evolve and improve. It is also a relative rather than an absolute scale, so that a city or town that is categorized as Type A (resilient) is relatively resilient compared to a Type B or Type C city or town.

Type 1 Division

Resilient Cities (Type 1a)

Type 1a SESs are in large urban areas comprised of either high- or low-density urban structures, primarily cities and metropolitan regions in which both inherent per capita resource supply and the institutions that facilitate access to those resources are quantitatively and qualitatively robust (Table 2). Type 1a SESs may provide insights to successful resource strategies, but they are typically the least challenging sites from a global resilience perspective. These SESs have enough social diversity (e.g., in values, institutions, and control) to initiate and maintain collective action, but not so much heterogeneity as to impede it over time (Heckathorn, 1993). Highly efficient and accessible transportation infrastructure enables easy access to and distribution of particular resources (Ardekani, 1992). A high degree of resource substitutability (e.g., multiple local and distant water supplies) enables Type 1a SESs to have greater and easier access to critical resources by creating resource redundancy.

Proactive management by institutions enables cities to have diversified economies (i.e., not dependant on one or a few economic sectors), as well as mixed use of natural resources from proximate hinterlands (Grant, 2005). Effective institutions are often critical in the mitigation of exogenous events. A key example of this capacity is successful control and management of floods by local government to lessen economic disruption and social impact (Plate, 2002).

Table 1 Features used to develop an initial typology of messy SESs and their links to the Institutional Analysis Development (IAD) Framework.

Feature	Components	Links to IAD Framework
Size	Boundaries	RS2–clarity of system boundaries RS3–size of resource system U1–number of users
Diversity	Social capital; land use; cultural integrity	GS4–property rights system RU1–resource unit mobility U6–norms/social capital
Distance	Resource use zone extension	U9–technology used RU3–interaction among resource units RU4–economic value RU7–spatial & temporal distribution
Retention	Efficiency (e.g., recycling)	RS5–productivity of system U5–leadership/entrepreneurship
Distribution	Equity, infrastructure	GS7–consititutional rules RU7–spatial & temporal distribution UP–technology used
Persistence	History, rigidity	U3–history of use U8–dependence on resource
Collectivism	Governance systems	GS1–government organizations GS2–nongovernmental organizations GS6–collective-choice rules
Variability	Location	RS9–location of resource system U4–location of users
Directionality	Import versus export	RU2–growth rate of resource RU4–economic value of resource RU7–spatial & temporal distribution
Substitutability	Control; range of goods and services' total costs	U5–leadership/entrepreneurship U6–norms/social capital
Communication	Diffusion of knowledge, decision making	GS5–collective-choice rules
Risk	Social, ecological	U6–norms/social capital

Table 2 Typology of messy social-ecological systems.

	Resilient			Mixed			Vulnerable		
	1a	2a	3a	1b	2b	3b	1c	2c	3c
Indicator	Vancouver CAN	Nishio JPN	Ganges CAN	Sao Paulo BRA	Al Qamishli SYR	King Cove USA	Dhaka BGD	Kati MLI	Vaiaku TUV
Diversity (land use)	High	High	High	Low	High	Low	Low	Low	Low
Distance (proximity to nearest source)	High	High	Low	Low	Low	High	Low	Low	Low
Retention (resource efficiency, e.g. mass transit)	High	High	High	Low	Low	Low	Low	Low	Low
Distribution (high-density, low socio-economic housing)	High	High	High	Low	High	High	Low	Low	Low
Persistence (limited or low net migration)	High	High	High	Low	High	Low	Low	Low	Low
Collectivism (public versus private institutions)	High	Low	High	High	High	High	Low	Low	High
Variability (e.g., water demand, availability, and potability)	High	High	High	Low	Low	High	Low	Low	Low
Substitutability (e.g., water sources)	High	High	High	High	High	High	Low	Low	Low
Communication (e.g., global connectivity)	High	High	High	High	Low	Low	Low	Low	Low
Risk (e.g., flood prone)	High	Low	Low	High	Low	High	High	Low	High

Vulnerable Cities (Type 1c)

Type 1c settlements reflect a serious challenge facing humanity: that of growing urban areas consisting mostly of poorly educated, impoverished residents, many of whom have immigrated from rural areas to pursue a higher quality of life through better employment or due to displacement from conflict and/or climate change (United Nations-Habitat, 2007). We anticipate that, with the increased frequency of environmental catastrophes, particularly in low-lying coastal areas, this SES type will become increasingly dominant and should be given special attention. These communities have relatively low resource access, limited collective institutions to acquire resources for the population, and a chronic inability to control the timing or volume of resource use. Vulnerability to exogenous events further limits the resilience of this type of SES; for example, poor roads or limited accessibility to food sources hinder settlement recovery from major disasters (Forbes et al. 2004). Adaptation strategies developed by communities or governments in this SES type must first address basic human needs before establishing approaches that involve cooperative institutions and innovative technologies. Because of this situation, Type 1c SESs must be considered differently from, for example, Type 1a or 1b SESs, where such approaches can variously address institutional dynamics and easily absorb risks of failure or trial-and-error. This distinction is important because interventions (e.g., aid) that maintain such SES differentiation are not simply mechanical processes; their potential withdrawal carries enormous emotional, moral, and political consequences. Additionally, the underlying circumstances that encourage the development of Type 1c SESs are often extremely complicated in their origins (e.g., resource extraction or manufacturing for first-world countries that diminishes or restricts indigenous access to critical natural resources), but simple in their outcomes (e.g., extirpation of local communities through migration).

Mixed Resilient/Vulnerable Cities (Type 1b)

Type 1b SESs reflect the heterogeneity of many high-density settlements around the world. Geographic domains or neighborhoods often exhibit properties of either Type 1a or Type 1c, but exist within the same political unit (e.g., a municipality). Such types are extremely complex and may require the most innovative strategies because the potential for conflict is enormous and the dynamics of local crises (e.g., riots), collapse, and response are extremely unpredictable.

Settlements of this type are highly divergent in access, distribution, and control of resources. These cities can respond effectively in some areas to exogenous events such as weather-related disasters, but the response is often uneven and large segments of the population—although not the overwhelming majority—receive inadequate assistance (e.g., New Orleans and Hurricane Katrina). Much of this divergence depends on the socioeconomic levels of the area and the disparity between resource availability and allocation. The quality and effectiveness of services vary greatly in these types of cities, even if institutions are well developed. Such urban districts have population segments that are resilient to certain social-ecological changes, whether drastic or subtle, but other segments are far less resilient. One such city is New Delhi, in which roughly 30% of the population did not have access to safe water in the late 1980s, leading to the widespread propagation of waterborne diseases (Table 2; Pelling, 2003). Included in Type 1b SESs are the periurban transition or tension zones that persist in the vicinity of large metropolitan regions–most prevalent in developing countries. In the typology, these districts could be treated either separately as peripheral areas or in conjunction with metropolitan areas as center-periphery complexes.

Type 2 Division

Resilient Towns (Type 2a)

Settlements characterized as Type 2a are towns (i.e., urban areas smaller than cities) that are able to adequately access, distribute, and control resources. Exogenous events affect these settlements, but in ways that are relatively minor or can be quickly mitigated. In terms of their characteristics, these locales are very similar to Type 1a cities. For instance, many of these communities have adequate infrastructure, a relatively diverse economy, mixed land uses, and substitutability or redundancy in the distribution and provision of resources (Table 2). Also, institutions are well established in Type 2a SESs, providing for a good level of resource control and response to exogenous events.

In addition to being smaller than cities, Type 2a towns have relatively low emigration rates. For example, in Western Europe rural migration from small towns into large cities slowed significantly at the end of the industrial revolution in the nineteenth century (Hochstadt, 1998). Type 2a towns are relatively self-sufficient within their regions and use many local goods and services. Some of these communities have developed mechanisms for autonomous government and depend on local agriculture (Day, 1998). Such indicators show less dependence on economic and sociopolitical activities than other towns and cities.

Vulnerable Towns (Type 2c)

Similar to Type 1c cities, Type 2c towns have a chronic inability to access, distribute, and control resources. Exogenous social-ecological events can have very acute consequences in these settlements, which often display poor infrastructure, weak institutions, and a low level of redundancy in resource use (Table 2). Unlike Type 2a towns, these communities lack characteristics that make them self-sufficient. Rather, many of these locales depend on goods and services from major cities or other resource providers. These settlements generally have low economic and land-use diversity, depending often on only a few core industries and land-use functions (Hinderink & Titus, 2002). Many inhabitants are transients who migrate to the town for short periods (Roberts, 2001). Type 2c SESs often have a legacy of rapid environmental degradation due to the types of industries or livelihoods that support them. Particularly challenging is the potential loss of cultural diversity, and hence adaptability, especially when Type 2b SESs choose to adopt land-use and economic activities that cannot be sustained over long periods.

Mixed Resilient/Vulnerable Towns (Type 2b)

Type 2b towns, similar to Type 1b urban areas, possess characteristics of both Type 2a and 2c SESs. However, the scale of social functions for these settlements is more constrained, thus affecting the strategies that they might adopt. Some areas of these settlements show capabilities in obtaining, distributing, and controlling resources, as well as in mitigating exogenous social-ecological events. Institutional infrastructure and capabilities are generally mixed, with some areas or population segments getting better service (Table 2). Many Type 2b towns were built to extract specific resources such as coal or oil. These towns can have successful economies, as occurred in Brazil in the late 1980s, but large segments of the population are migratory workers and/or low-wage earners dependant on undiversified land use and economies (Godfrey, 1990). These characteristics show aspects of social and ecological resilience, but are threatened by degradation in the undiversified economic and ecological resources on which they depend (Ryder & Brown, 2000). However, unlike Type 1b cities, Type 2b towns generally have greater familiarity and connectivity within and between social networks, partially due to their smaller scales. Thus, approaches that address these aspects of social-ecological phenomena are more likely to produce desirable outcomes than in Type 1b cities.

Type 3 Division

Resilient Villages (Type 3a)

This settlement type represents villages that have good access, distribution, and control of resources, and the capacity to respond to external social-ecological events. Such villages may display some similarities to large towns with relatively well functioning institutions and effective resource management (Table 2) that sustain ecosystem services in the long term. One distinguishing characteristic of these communities is that they are reasonably self-sufficient in basic resources (e.g., food and water) and can easily exchange or obtain nonessential resources (e.g., mechanized equipment). These villages exhibit some redundancy with respect to the sourcing of basic resources, for instance having rotating agricultural field systems and crops or being able to hunt several species in multiple areas. Residents in such communities do not emigrate at high rates, preserving local knowledge that enables these villages to perpetuate skills useful for resilience practice. Examples of such communities include Amish settlements in the United States (Zook, 1994) and some *kibbutzim* in Israel (Ben-Rafael, 1997). The argument can be made that of all the SES types, these settlements are the most robust at adapting to social-ecological changes caused by internal community needs (e.g., water and food demand), but are not as resilient as Type 1a cities to exogenous events. For example, Type 3a villages may not have adequate medical facilities, resources, and personnel to deal with a pervasive disease or with large-scale disasters such as earthquakes.

Vulnerable Villages (Type 3c)

Showing a near total lack of basic resource allocation, distribution, and control, Type 3c villages are typically found in impoverished areas and may survive primarily on outside aid (Table 2). They are very susceptible to outside social-ecological events that can induce collapse or outright destruction. Typical characteristics of these settlements include high rates of emigration to urban centers, dependence on outside goods and services, poor infrastructure, and chronic to acute resource shortages. Type 3c villages can be found in rural Botswana and in the Democratic Republic of the Congo (Mbenza, 1995; Tesfaye & Asefa, 1999).

Mixed Resilient/Vulnerable Villages (Type 3b)

Villages of this type display characteristics of Type 3a and Type 3c. They have adequate access, distribution, and control of some critical resources. Some resilience to exogenous events is also evident. Such communities, however, are often limited in resource quantities and in their capacity to distribute goods and services. Vital resources such as water are often difficult for households in Type 3b villages to obtain locally or are in short supply, hindering resource self-sufficiency (Table 2). The economies of these communities often depend upon one or a few primary sectors. These characteristics promote vulnerability, particularly if resources are disrupted or there is significant change in the regions' economic role. Examples can be found in Alaskan villages that have a heavy dependence on undiversified resources (e.g., salmon for food), as well as oil for heating, transport of goods, and local travel to obtain subsistence food (e.g., by snow machine, all-terrain vehicle, boat, or small airplane) (Ellanna & Wheeler, 1989). Included in Type 3b divisions are low-density agroforestry or horticultural landscapes.

Discussion

Using tenets from the SES typology (Figure 1) and components of the messy SES types outlined above (Table 2), we set out some generic characteristics for each SES type (Table 3). In this framework, collectivism constitutes the ability to recognize past successes and failures, including rigidity, and to alter institutions, built environments, and technology to avoid future failures and to optimize successes. Social networks constitute functional affiliative and familial ties and are most intact in Type 3a SESs with limited immigration and emigration. Functional diversity, response diversity, and exposure to catastrophe (disaster versus seasonal events such as monsoons) reflect a type's stability. For example, a Type 1a SES is fairly stable due to sustained equilibria across components and scales (e.g., socialized services, regulated minimum wages, diverse supplies of food, plentiful water) whereas a Type 1b SES appears stable, but has clusters or zones prone to vulnerability (e.g., socioeconomically disadvantaged neighborhoods that can rapidly develop acute resource shortages requiring external aid or discontent leading to social unrest, even riots). Variability reflects the possibility of emergent social and physical structures such as hierarchies, novel policies, and coupled sociotechnological interventions. Substitutability reflects a settlement's social and ecological wealth. Social capital includes knowledge and capacity for innovation and is generally higher in SES types where basic human needs (e.g., water and sanitation) have been met. Rigidity reflects the inability of settlements to adapt physically and socially to changing conditions, especially if unexpected. An example is

Table 3 Characteristics of messy SES types.

	1a	1b	1c	2a	2b	2c	3a	3b	3c
Diversity	●	●	○	●	●	○	●	○	○
Distance	●	○	○	●	○	○	●	●	○
Retention	●	●	●	●	●	○	○	○	○
Distribution	●	●	●	●	○	○	○	○	○
Persistence	●	●	●	●	●	●	○	○	○
Collectivism	●	●	●	●	●	●	○	○	○
Variability	●	●	●	●	●	●	○	○	○
Substitutability	●	●	○	●	●	○	●	○	○
Communication	●	●	●	●	●	●	○	○	○
Risk	○	○	○	○	○	○	●	●	●

● Higher levels, plentiful, well developed, and so forth.
○ Lower levels, scarce, poorly developed, and so forth.

built environments engineered to serve multiple purposes or tolerate extreme ranges of conditions and, on the social side, norms and cultures that accept uncertainty and instability as manageable.

We speculate that five general propositions will arise from this typology, building upon Walker et al. (2006). First, size matters. Smaller settlements in resource-rich areas, despite having less social capital than larger SES types, have a stronger ability to supply basic needs and are often highly resilient (Type 3a), but with increasing size social capital allows settlements to produce and acquire resources from broader scales that may approach global scope. However, the tradeoffs in social resilience, such as decreased dependence and awareness of geographically local environments, may result in vulnerabilities that are only acutely realized when marked change (e.g., a natural disaster) interrupts supplies (Type 1a). In other cases, the opportunities perceived to exist in larger settlements can result in vulnerabilities, for example, rapid regional immigration leading to water shortages and disease spread that becomes difficult to reverse (Type 1c). This proposition raises the boundary issue of whether the SES typology could help us understand if cities or towns can address the sustainability problems they cause, or contribute to, outside of their local boundaries through excessive resource consumption and its related emissions. It is not possible to address this important issue here, but this point should be a priority in future refinement of the typology.

Second, inherent resource abundance is critical (Auty, 2001). Shortages of key provisions such as water can be mitigated only if social organization allows human actors to sustain effective collective action. Relevant responses could include modifying behaviors so that they are consistent with limitations imposed by the local environment, as well as adopting technologies that are sustainable over long periods. Type 1a cities may employ technology to overcome inadequate local resources, but Type 1c cities generally have no effective means to counter critical resource shortages. For example, affluent Persian Gulf countries can address water shortages with desalinization technology, but poorer arid countries generally do not have this option (Al-Mutaz, 1996), increasing vulnerability particularly in the short term.

Third, diversity in both social and biophysical systems is necessary for SESs to accommodate perturbations such as the loss of a crucial market or a catastrophic event. Multiplicity and redundancy, attained by investing in knowledge economies and having numerous commodity niches, promote the ability of settlements to adapt to new social circumstances as local and global conditions change.

Fourth, technologies, including infrastructure, must be accessible and function over long periods to distribute necessary resources, such as water and energy. Vital infrastructure must be efficient and redundancy must be resilient to exogenous events (Kassis, 2005; Coaffee, 2008). Settlement infrastructure, however, must be flexible enough, both socially and physically, so that sunk costs do not prevent rapid adaptation, a significant challenge in built environments. For example, the Brazilian city of Curitiba was able to quickly modify its urban transportation system in response to harmful commuter patterns (Rabinovitch, 1992).

Fifth, settlement management and effective governance is necessary. Settlements that plan and organize well, making good decisions regarding use and development of ecosystem services, are able to adapt. Such settlements make prudent collective decisions, balancing tradeoffs between growth and sustainability. Settlements with shared values and beliefs and equitable wealth distributions are better able to promote resilient practices (Folke et al. 2005; Alessa et al. 2007). Related to effective governance and management organization, reinforced and protected social values and networks enable settlements—particularly small-scale urban environments—to be more adaptable to external and internal shocks (Berkes et al. 2003; Alessa et al. 2008). Conversely, ineffective governance and management (i.e., resulting in gross inefficiencies and poor outcomes) can lead to settlements being less able to adjust to evolving social-ecological states that can cause significant stress.

The typology presented here is a first attempt to evolve the concept of neat SESs, or those with relatively clear system interactions, toward messy SESs. We believe that messy SES types will possess different dynamics of resilience and varying capacities to adapt to change, and ultimately require different approaches to management. In some SESs (e.g., Type 1c-3c), failure to develop adaptive strategies may mean acute morbidity and mortality, whereas in other SESs (e.g., Type 1a-3a) it may mean reduction in the range of goods and services. Researchers must address such differences carefully, since different rules and consequences will guide locally relevant management and adaptation strategies to avoid poor outcomes. Strategies adapted to address vulnerable settlements need to consider the specific circumstances that make such communities susceptible to untoward risks. An effective typology can provide a comprehensive means for researchers and stakeholders to evaluate settlement vulnerability and to subsequently develop appropriate strategies. That is, typologies useful in evaluating settlements based on the aggregate variables affecting resilience, and within a range that shows both aspects of vulnerability and resilience for various urban environments, may prove better in developing community-management and adaptation strategies than a neat SES. The variables that each indicator describes (Table 1 and 2) have potentially useful diagnostic value for understanding messy SESs. While Type A (resilient) and Type C (vulnerable) SESs represent the obvious diametric ends of the continuum, Type B (mixed or transitional) SESs are likely to be the most challenging as their combinations of indicators could prove particularly complex from a management perspective.

Conclusion

We have proposed that messy SESs need to be better refined to identify the most appropriate adaptive strategies for a given SES type. Nomadic and provisional settlements, such as refugee camps, have not been considered, but we have attempted to create a classificatory system that is applicable to most established habitation systems. Further refinement of this SES typology requires incorporation on a mass scale of the technologies upon which settlements rely. It also suggests a need for the engagement of diverse communities involved in understanding systems in general (e.g., physicists and biologists). The way a cell and a city function are remarkably similar. Both must selectively acquire and distribute resources to maintain specific functions such that the overall system operates continually and optimally. For example, a moderate degree of diversity is important in the functioning of SESs (Elmqvist et al. 2003), a concept comparable to the Law of Requisite Variety that there exists an optimal variety of actions available to a control system: too many and it becomes disorganized, too few and it becomes rigid (Ashby, 1956). Similarly, in cellular systems, the ability of the cytoskeletal array to reorganize quickly in response to stimuli (Alessa & Kropf, 1999) is comparable to the idea of flexibility in SESs (Walker et al. 2002).

In closing, we emphasize once again that our typology for SESs represents a continuum rather than a set of discrete categories. We recognize that larger settlements can display different aspects from the categories proposed. For example, Chicago has elements of resilient locales and also large areas that resemble transitional SESs. A simple tenet governs our species' life on earth: we seek the ability to acquire natural resources for material transformations that meet human needs and desires in sustainable ways. This quest has generated strategies that optimize adaptability and well-being. We believe that without a typology that better describes messy SESs, and ultimately more refined "best practices" for decision support systems and adaptive responses, meeting this goal will be difficult.

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