Chapter 3: The Human-Environment System

The overarching puzzle of sustainability science is this: How can we transition to a world in which the needs of humankind can be met without threatening the life support systems of Earth? This challenge addresses a basic relationship between humans and their reliance on the environment and resources of the planet. Conceptualizations of sustainability are built from rich intellectual traditions about the relationship between nature and humankind, originally focused on land degradation and resource depletion in antiquity,[1] subsequently crafted into general theories about the relationship, and currently evolving in scope to embrace the contemporary understanding of human impacts on environment at a global scale and the importance of those changes for human well-being.[2] At its heart, the concept of coupled human-environment systems (also termed social-ecological systems, coupled human and natural systems, and coupled human-biophysical systems)[3] recognizes that the social, economic, and cultural well-being of people depends not only on their relations with other people, but with the physical and biological environment as well. These relations transcend the environment as stocks of resources (e.g., fresh water) to the capacity of the environment to function as a life support system (e.g., climate). The coupling of people and environment ranges across spatial and temporal scales, from the local and short term to the global and long term. It also involves relationships that vary in scope from relatively simple to extremely complex system interactions.[4]

[Figure 3.1 near here]

3.1 The Coupled System

A coupled human-environment system or CHES (Fig. 3.1) involves interactions and feedbacks between its human and the environment subsystems, and with other CHESs. In either case, the dynamics involved are highly complex, often synergistic, and rarely deterministic.

The processes and consequences of the two subsystems are so tightly and dynamically intertwined that each affects the structure and operation of the other with constantly adjusting outcomes for either system, illustrated by the fluctuating line in Figure 3.1. In some cases the coupling of systems are so strong that either subsystem or attributes of the subsystem may be viewed as *co-adapted* with the other. Parts of the grasslands of sub-Saharan Africa are a case in point. Owing to thousands of years of human burning mixed with natural fires, the proportion of grass-cover relative to tree-cover in some open woodlands and savannas has been enlarged and maintained, providing the appearance of a natural landscape and supporting large herds of livestock and native herbivores.[5,a] Without this scale of repeated burning, tree cover would enlarge with impacts on the carrying capacity of grasses to support the scale of grazing that takes place on them. Studies in Australia have also demonstrated that the abundance of tree species in "wildlands" there is also a product of long-term burning in the past by Aborigines.[6,b]

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[a] Ask Mark Stafford Smith

[b] Pam suggests that we leave this at coadaptation and not get into coevolution

These kinds of couplings essentially mean that processes crossing the two subsystems analytically must be treated as endogenous.

The structure and function of any coupled system or its subsystems affect and are affected by other coupled systems of the same kind (content and scale) and by linkages to other systems operating at different spatial-temporal scales (green arrows in Fig. 3.1). For example, the apparent decline in wildebeest herd sizes in the Masai-Mara reserve of East Africa has much to do with changes in land cover beyond the reserve. The property rights of pastoral peoples that had evolved over the centuries to fit with the ecology of East Africa, were dramatically altered under colonial and post-colonial rule in Kenya. This change added considerable stress to grazing areas and to the Maasai themselves.[7] More recently, the growth in mechanized agriculture within the wildebeest breeding and calving grounds appears to be a trigger mechanism for herd size declines.[8] Changes in land uses in one location, thus affect the population of a keystone species in another location. Such connections are increasingly demonstrated, especially for reserves and parks established to preserve biotic diversity.[9]

These complications make it difficult to develop simple frameworks for analysis, and often lead to the necessity of a step-by-step or nested kind of analysis. In the following section, we illustrate the various levels of interactions in the coupled system that ultimately must be included in any assessment or analysis.

3.2 Unpacking the Coupled System

There is, of course, no one CHES, but many such systems, operating in different places and in different spatial and temporal dimensions (e.g., local and short term to global and long term). The resulting interactions moderate and mediate the ability of any particular CHES to meet people's needs sustainably.

3.2.1 Proximate Interactions and Environmental services

At the most basic level, the immediate or proximate interactions are between a human use subsystem and an environmental subsystem (Fig, 3.2, A). This interaction involves the attempts of people to manage (e.g., pastoral nomadism or suburbanization) the environmental subsystem, usually the local ecosystem (e.g., prairie or floodplain), in order to obtain expected *environmental services*, especially those labeled provisioning services, such as food, water, clean air, medicines, and raw materials for construction, and cultural services, such as forested areas, recreational space and sacred landscapes.[10]

The advance of the anthropocene has witnessed profound growth in the demands for provisioning services (or resource stocks). The technologies developed to deliver them, as well as waste and by-products in their production and consumption, have develop sufficiently to affect directly the structure and function of the environmental subsystem with consequences for regulating and supporting services. Examples include climate and disease control (regulating) and crop pollination and the cycling of nutrients (supporting). Proximate interactions in a CHES, therefore, must expand to consider these impacts. For

example, repeated crop-fallow cycles in shifting cultivation in the southern Yucatán has depleted available soil phosphorous sufficiently that it affects the quality of the secondary forest in the fallow cycle. Thus, these cycles have also affected the replenishment of soil phosphorous for the next round of cultivation—a replenishment that farmers expect in the fallowing process as well as the time span needed to regenerate secondary forests into mature forests.[11]
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3.2.1 Relationships of Human Needs and Wants with Environmental Services

The history of human-environment relationships has focused on provisioning services, conceptualized and treated theoretically as resources or resource stocks (also natural capital).[12] No such conceptualization has captured more attention than that postulated by Thomas Malthus in his six editions of *An Essay on the Principle of Population*, which treat the relationship between population growth, food production (stocks), and technology.[13] To simplify, the Malthusian view postulates that the capacity of population to grow more rapidly than food stocks invariably leads to a potential of the population to overshoot of those stocks. Unless checks on population growth occur, the overshoot triggers what has become known as a Malthusian crisis. Food stocks, or more broadly resource stocks, limit the growth in population because, in this view, food production typically resides at its technological limits and advances in technology (and societal organization) that would raise the limits are conceived to operate independently of the population-resource stock relationship. Subjected to extensive critique, the limits to population growth permeate the intellectual history of human-environment relationships and are embedded in such concepts as ecological or environmental carrying capacity.[14]

In the *Conditions of Agricultural Growth*, Ester Boserup reversed the "limits" concept. In the Boserupian scheme, population growth triggers the use of more intensive food production practices, which permits that production to keep pace with the demands from more people. This relationship holds because land managers do not employ the highest level of management practices (or technology) available to them. Rather, owing to inputs costs, especially (the drudgery of) labor, they employ practices consistent with the levels of pressures placed on them. In this sense, technology (and implicitly societal organization to use it) is endogenous in the CHES; indeed, various research indicates that the innovation of technology itself is induced by the demands of population, leading to the concept of induced innovation and intensification.[15]

Variants of these two themes can be found in a large range of research addressing CHES and resource stocks. At least two adjustments to them are useful here. They involve the mediating role of institutions and environment on the population-resource stock relationship. Governance arrangements (e.g., the institutional rules that individuals use to regulate their interactions at multiple scales) can moderate or exaggerate the demands that humans place on resource stocks (North, 1990, 2005). Given the complexity and changing nature of ecological systems, institutional arrangements must also be complex, adaptive, and organized at multiple scales (Ostrom, 2007). The environmental subsystem also mediates the intensity of food production (or farming practice) and rates of changes in it. Use of marginal and prime agricultural lands, for example, amplifies or attenuates the production responses under different levels of pressure.[16]

In contrast to provisioning services, regulating, supporting, and cultural services have received far less attention in human-environment frameworks. Throughout most of human history the societal impacts on these services were negligible, save in some localized cases. Nature absorbed the human disturbance sufficiently to permit the regulating and supporting services to restore the provisioning ones. In this sense, humankind typically placed little economic value on these environmental services that appeared to be infinite and free. Two well know contemporary examples are climate change and the thinning of the ozone layer in the stratosphere. In either of these cases, societal and economic structures have long operated under the assumption that the externalities of resource production and consumption did not involve costs of changing climatic conditions or loss protection from ultraviolet radiation. These regulating services and supporting services were not considered in any accounting systems of resource use, although attempts are now underway to incorporate them, as in the case of the Kyoto Protocol and climate change.[17]

3.2.2. Beyond Proximate Interactions

CHES's involve more than immediate or proximate interactions, however, because any system is influenced by and influence other parts of a coupled system. In the shifting cultivation example above, the soil resources and thus food provision are influenced not only by changing proximate interactions with human use (Fig. 3.2, A) but are also influenced by the biophysical setting (e.g., parent material [rock type], level of soil development, microclimate, and biological organisms in the area, and the history of previous land uses - B) and the socioeconomic setting (e.g., population pressures, markets, land tenure - C). In turn, land-use decisions (e.g., about use of fertilizers and other management practices) may have consequences that transcend the proximate interactions, affecting the larger environmental and social context (D). For instance, land clearing and hydrological changes in southern Florida have altered the surface sensible and latent heat flux that ultimately decrease regional precipitation and increase the diurnal temperature cycle, affecting the long term water balance of the region.[18] Changes in this water balance—a product of impacts on regulating and supporting services—affect the functioning of the Everglades reserve, the large-scale sugar cane production south of Lake Okeechobee, and, of course, the large and rapidly increasing demands for potable water in the Miami-Atlantic shoreline megalopolis.

Myriad examples exist to illustrate interactions within and across human-environment systems.[19] Depending on the specific problem addressed, these interactions serve as drivers of change and stressors on the vulnerability and sustainability of a CHES. The demise of the Aral Sea, for example, involved a hierarchy of stressors ranging from the immediate action of withdrawing massive amounts irrigation of water from the Sea's only two tributaries to local demands for employment from an rapidly increasing population to pressures from the Soviet state to generate cotton in order to generate foreign currency.[20] Likewise, the vulnerability of farming systems on the southern Great

Plains of the United States was stressed by extended drought, inappropriately applied farming practices, and the Great Depression which affect the ability of the economic system to respond to plight of smallholder farmers.[21]

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[Figure 3.2 somewhere near]

Unpacking any of the processes in a CHES invariably reveals interactions and feedbacks between the proximate interactions and the broader human and environmental subsystems, as noted in the south Florida example above. The environmental subsystem is comprised of components and flows operating from the ecosystem to earth system level, and ultimately involve links between the land, oceans, and atmosphere.[22] These linkages are simplified here (Fig. 3.2) to illustrate those between ecosystems and earth system as they affect environmental services. Less consensus exist about the human subsystem model, but its basic structure and function is captured by several different efforts.[23] It is also simplified here (Fig. 3,2) to capture the population, technological, economic, and governance components of societal structure, each of which has been empirically and conceptually linked to use systems.

The environmental subsystem sets the ambient biophysical conditions for the proximate interactions, influenced by "natural" processes and by various human impacts on it, intended and unintended (Fig. 3.2, B). The human subsystem establishes the demands on (i.e., economy, population), rules of access, management, and use of (i.e., governance), and the capacity to produce and consume (i.e., technology) natural resources and related ecosystem services (C). In addition, linkages that initially by-pass the proximate interactions in question may have profound, indirect affects on either subsystem (Fig.3.2, E). One of the more notable such interactions is that between fossil fuel burning and industrial emissions in the Ganges Basin which, coupled to the physiographic and atmospheric conditions of the basin, leads to air pollution events that ultimately reduce rice yields.[24] In this case, tropospheric pollution affecting the agricultural production arises from those components and interactions of the coupled system residing in the same general location but not immediately part of the agricultural system, an interaction thought to take place at the continental scale as well.[25] This hierarchical embedding of system interactions in place may also be considered a cross-scale coupling, illuminating the complexity of CHESs.

3.3 Complexity of the Coupled System

CHESs are characterized by within-scale and cross-scale interactions that vary over time and space, that are often non-linear and with thresholds, and that involve reciprocal feedbacks loops. They are, in other words, highly complex systems (Figures 3.1-3.3).[26] Much of the complexity is derived from their structure involving systems within systems within systems.[27] This complexity suggests that analysis of CHES's requires explicit examination of hierarchical couplings, across spatial and temporal scales and tiers of organization, with attention to differential effects in different places.

Perhaps one of the greatest advances in our understanding of the Earth as a system is the degree to which human-environment systems are linked to each other not just by economics, transportation, and policies, but also by the movement of materials and information through air and water systems and through "teleconnections" in the planetary circulation systems.[28] Coupled system assessments must consider these cross-scale interactions because of their profound implications on the sustainability of any human-environment system. The local system is not only connected to other spatially adjacent ones (Fig. 3.1), but to spatially ascending scales of conditions and process, such as those operating at the regional (landscape), national, and global (earth system) levels (Fig. 3.3).

The linkages may operate from the top down or the bottom up. Take for example, the recent deforestation in the Amazon owing to the spread of large-scale soybean production. This phenomena is linked to decisions in the United States to subsidies corn-based ethanol—an inappropriate response to potential reductions in carbon emissions—which reduced soybean production among American farmers, driving up the price of soybeans on the international market and providing an incentive to change land uses in the greater Amazona, including pushing cattle production deeper into the forest lands.[29] International and national policies on agriculture and land tenure may play out very differently among and within countries predicated on the CHES in question, especially as social and natural capital differ.[30] For instance, tree cover has increased in El Salvador, even under high population pressures, as a result of several factors, including international linkages involving outmigration and the development of a remittance economy that reduces the area cultivated.[31] Embedding hierarchies of spatial or organizational scale in analyses of human-environment systems follows on the concept of "progressive contextualization."[32]

[Figure 3.3 near here]

Adding to this complexity, processes within and crossing systems operate on short- and long-term temporal scales (Fig. 3.3). Take, for example, the shifting agro-ecosystem briefly discussed above for southern Yucatán. Within this system, annual market variations or local policies intended to assist smallholder farmers may trigger rapid land-cover changes at the local level without the requisite cropping inputs (e.g., fertilizers), affecting the capacity of the ecosystem to replenish withdrawn soil nutrients, an otherwise mid-term (e.g., multi-decadal) process built into longer fallow shifting cultivation (Fig. 3.3, A). The accumulation of these land changes across adjacent ecosystems can change the responses of secondary vegetation, surface hydrology, and evapo-transpiration sufficiently to change regional (landscape) level precipitation characteristics over the short run,[33] and biodiversity and carbon dynamics over the longer term (B).[34] Indeed, repeated local-to-regional scale land transformations, especially deforestation, constitute the second largest source of CO_2 to the atmosphere (behind fossil fuel burning), contributing to global climate change (C) with its obvious consequences on vegetation, biotic diversity, crop production, and water across the earth (D), often with considerable lag times between the triggering activities and the societal or environmental response.[35] The climate feedbacks on the production systems or responses to climate change reverberate back to agricultural markets, and in time, affect international accords and migration. Returning to the corn-ethanol-soybean example above, the resulting deforestation in Amazonia ultimately has major implications for global biodiversity and climate change.

For complex lake systems located in North America, the relevant temporal scales may range from several days to around 12,000 years, when one takes into account a dam breaking in the short term or the time since the last ice age. The relevant spatial scales for analyzing diverse human-environment interaction may also range from a single lake to the more than 7,500 lakes in the Northern Highland Lake District of Wisconsin in the U.S. include up to 65,000 permanent residents and thousands of summer visitors.[36]

One of the major advances in understanding of Earth as a system and of the role of humans in it has been the recognition of the importance of legacy effects and time lags. Today, ecological and social theories both recognize the cumulative effects of past conditions on current and future aspects of the human-environment system. Historical land use, natural and human-caused disturbances, and past climate and spatial connections, for example, can dramatically influence the conditions and provisioning potential of an ecosystem. Major short-run changes in the market prices for coffee, for example, can have major long-run impacts on local ecologies and economies as residents cut down trees and plant coffee, only to find that the price for coffee drops dramatically as the coffee plants mature and their have lost substantial assets without a major improvement in their economic well being.[37] In such cases, the land investment undertaken are not easily abandoned and replaced; investors may seek alternative income-generating strategies, banking on future increases in the value of the coffee. Thus the initial investment to convert the agro-ecosystem to coffee may create path-dependent conditions—those which determine what future options are available for the CHES in question. The consequences of slow-changing variables in the system, as well as time lags between action and detection of results, complicate both the analysis and the management of human-environment systems.[c]

Another characteristic of complex, human-environmental systems is diversity. The importance of biodiversity – the incredibly rich variety of genes, species, and ecosystems that have evolved over time – in terms of ecosystem and global system function has been debated and discussed for decades. Many studies suggest that diversity (including functional diversity as well as species diversity) frequently enhances the resilience of an ecosystem to survive major disturbances (e.g., fires, floods, and draughts) . Life at its most basic level is characterized by immense diversity, demonstrated by breakthroughs in sequencing human and animal DNA and the immense variation in the genetic code found across individuals.[38] Unrecognized and unobserved diversity of species within cod fisheries, for example, has led to major overharvesting when subpopulations are aggregated without recognition of the localized breeding habits of these populations.[39] Human institutions are also characterized by diversity. Empirical research, for example, has identified over 27 different boundary rules that are used in the governance of resources systems that draw on attributes of potential users including such variables as residency, personal characteristics (e.g., age, gender, education or skill level), or their

[c] An example is required here?

short or long-term relationship with a resource.[40] Authority rules are also used to regulate what type of harvesting or maintenance activities are required or permitted and research has identified over 100 authority rules used by existing systems around the world. Given the equally large number of information, position, aggregation, scope, and payoff rules, the diversity of rules that creative problem-solvers have adopted over the globe is immense. Understanding why diversity of some forms generate stronger systems that are able to be more productive in the short run and resilient in the long run, while other forms of diversity add costs to the relevant process is a pivotal question of sustainability science.

Finally, the prevalence of non-linearity among variables of interest in the human-environment systems, and thresholds or tipping points beyond which the fundamental relationships no longer hold, represent perhaps the greatest challenge to the analysis and evaluation and management of human-environment systems. Analysis of tipping points is systems as diverse as Wisconsin lakes[41] and the global climate system[42] indicate the ability of human environment systems to transition rapidly and surprisingly from one state well-suited to sustaining people and their resource needs to another that can no longer meet similar needs. Large shifts in the fishing stock of a lake can be the result of processes that have slowly occurred over decades, such as the accumulation of chemicals from the application of fertilizer on agricultural plots or rapidly as new anglers discover a lake and use it intensively or alternatively as a result of storms.[43] Understanding these thresholds, detailed in Chapter x of this book, is key to increasing the probability of sustaining important ecosystems and the humans that depend on them.[d]

These and other elements of complexity have significant implications for management of CHES's. Indeed, it is the failure to include them in one way or another has probably led to the plethora of management and development failures that abound in the historical and international experience, be it the collapse of some early civilizations or that of the Aral Sea.[44] While the need to account for complexity of human-environment systems is recognized, analytical examples of them are in their infancy.[45] Indeed, much of the research on environment and development still struggles to simply integrate humans into ecosystem analysis, or conversely, to include biophysical systems in socioeconomic analyses.[46] Nonetheless, new approaches and frameworks for analysis of complex human-environment systems are now emerging and some of them will be developed more fully in further chapters.[47] New and improved tools, including remote sensing, agent-based modeling, spatially-explicit GIS models, and meta analysis of the increasing numbers of analyses are critical tools within those analytic frameworks.

Ultimately, a perspective that focuses on CHES's and attempts to explicitly understand and evaluate interactions across scales of time and space is the fundamental underpinning of sustainability science. A focus on human environment systems drives interdisciplinary research and action toward more complete and systematic evaluation of critical challenges and potential solutions that work on the ground and at multiple scales.

3.4. Common Dimensions of Coupled Systems

[d] We not yet added Shellnhuber or butterfly effect..may be need help from others

The CHES approach is systemic in character, searching for general attributes of systems that provide clues about sustainability for both people and the environment. To achieve this goal requires a coupling of the processes underpinning each subsystem and a determination of the outcomes given the complexities of each coupled system, itself embedded in location and moment. Human demands on and means of procuring from nature strongly affect these outcomes. Thus much attention has been give to base drivers of the human subsystem. These, of course, vary by coupled system and by scale of analysis. Over the longer term and at the global scale, population, affluence, governance, and technology prove to be important; indeed they are present in every CHES, although their roles are amplified and attenuated by the case in question.[48],[e]

This observation should not be surprising. Population numbers and affluence (or consumption per population) capture gross demands on the environment derived from needs and wants of our biological number and our differential capacity to obtain and consume them, largely registered in wealth. As these two base demand factors increase globally, so does the pressure on provisioning environmental services (resource stocks) and, in turn, on the regulating and supporting services. In a globalizing world, there need not be a spatio-temporal congruence of these demand factors and their environmental consequences. It is well known, for example, that deforestation in Borneo, Amazonia, and other tropical forest locations is ultimately linked to demands for wood, beef, and soybeans in first and second tier economies, and registered through international hierarchies and networks of markets.[49] Similarly, the impacts of this deforestation on the Walker Circulation, atmospheric CO_2 and ultimately climate change are delayed, in some cases decades or more, as the scale of the activities reach proportions to affect the earth system.[50]

Governance, or more specifically institutions directing access or entitlements to resources mediates the pressures of the population and affluence.[f] They do so in several ways: by determining who and how property and resources are accessed, which can be foundation for sustaining or destroying the viability of an economic exchange system; by affecting the capacity of populations to migrate or the level of societal safety nets extend to people; and by structuring which technologies can be used for harvesting resources, such as requiring appropriate fishing gear that does not destroy the sea floor of an inshore fishery or capture and destroy immature fish along with the desired quantity of mature fish. Technology determines the level of impact (e.g., CO_2 emissions, soil nutrient depletion) on the production and consumption generated by the forces above.[51] Waggoner and Ausubel (2002) divide this factor in two: intensity of use and efficiency of production. Dematerialization, part of industrial transformations underway, is an example of use intensity.[52] Production efficiency refers to the totality of impacts from consumption, and

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[e] The question here is do we stick with PAT (the most known) or the Kates version P x consumption/p x impact per consumption—or do we work this in? In fact, PAT implies Kates

[f] Pam suggests that Governance be placed after T because Governance affects PAT. This we need to consider. Over the long haul (the three step historical curve in C2), T is the independent variable that changes P and A. In the conceptualization above (text) PA and Gov are seen as demand factors and T, the impact factor.

is typically registered as energy efficiency, such as home heating per household and kilometers per liter of vehicles. In theory, efficiency applies to more than energy, and includes the unit impact on the functioning of environmental systems. For example, the organization and management of agriculture has consequences on the earth's albedo, evapotranspiration, and the nitrogen, phosphorous, and carbon cycles.[53] It is noteworthy that the existence of technologies that reduce environmental drawdown does not necessarily imply that they will be employed, leading us back to the role of economics and governance in affecting the employment of technology.[54]

Recognizing the roles of population, affluence, institutions, and technology on the state and operation of CHES's is not inconsistent with the central message that human-environment systems are complex. As Lee noted in his treatment of population-resource dynamics, the general principles operating are basically understood but the complexity of the interactions by time and place can spin the coupled system into Malthusian or Boserupian spirals.[55] The precise mechanisms leading to either spiral have proven elusive to identify and highlighted the need for place-based assessments of outcomes. A major challenge confronting sustainability science is the search for the combinations of mediating factors that promote CHES's to be more or less sustainability.

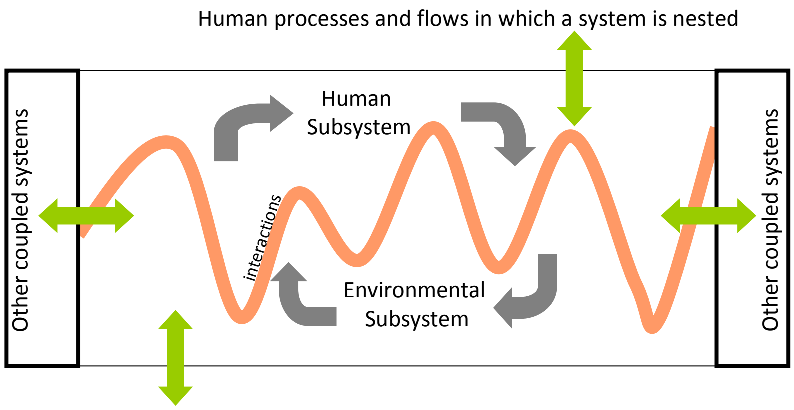

Fig. 3.1: The coupled human-environment system overview

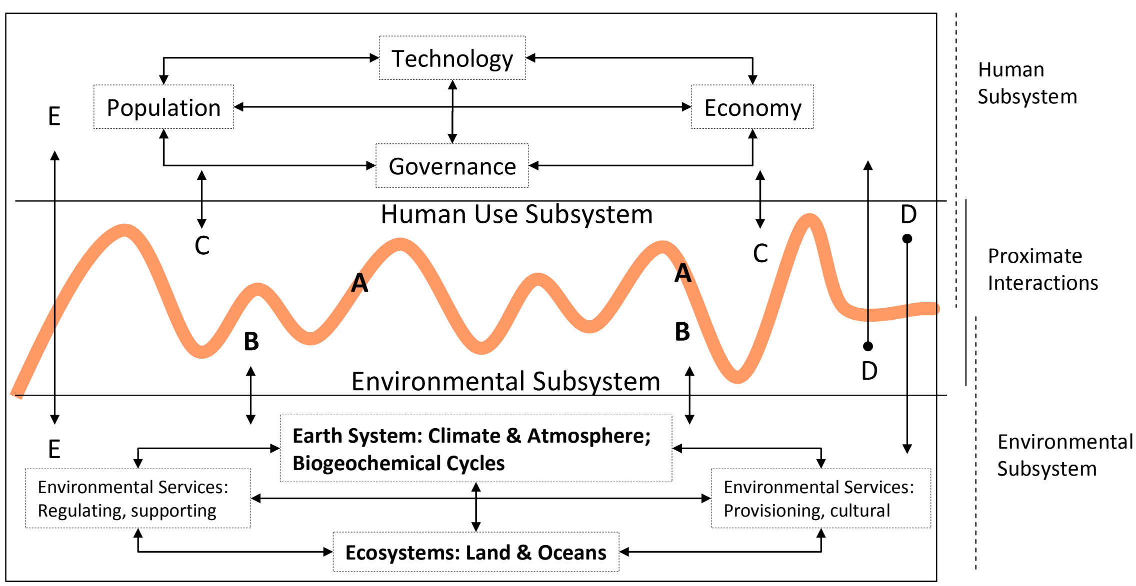

Fig. 3.2 Inner-workings of Coupled Human-Environment Systems

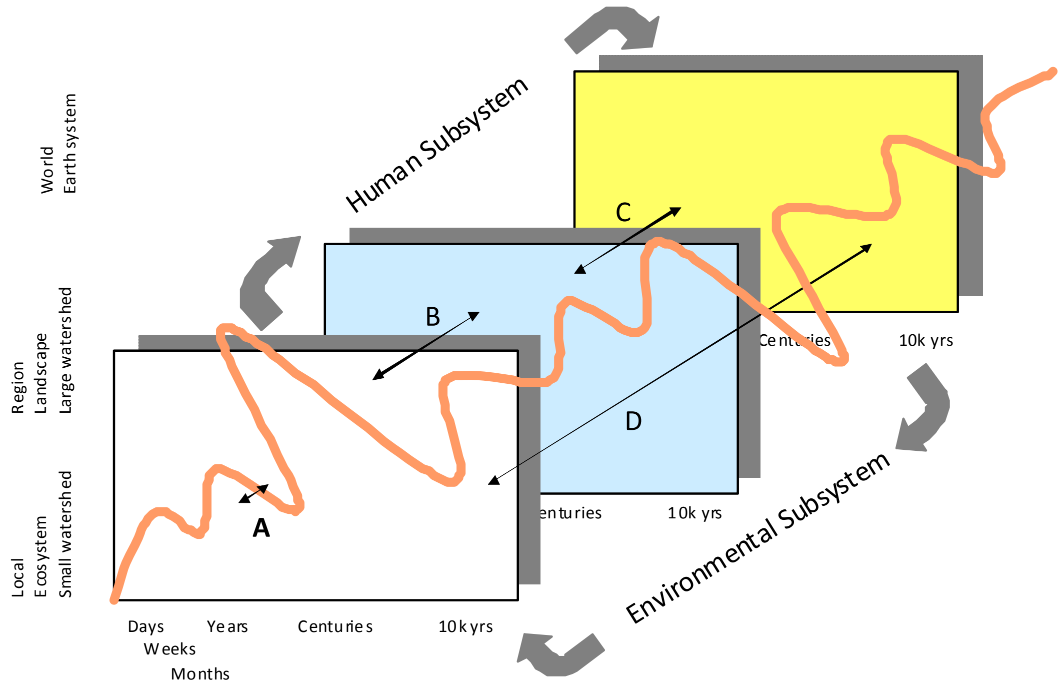

Fig. 3.3: Process and flows across scales of systems

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NOTES:
[1] Shafer (1962), White (1967), Tuan (1968)
[2] IPCC (2007a-b), Steffen et al. (2004); Turner et al. (1990)
[3] Folke (2006), Liu et al. (2007), Ostrom (2006); Kotchen and Young (2007)
[4] NRC (xx), MEA (2005)
[5] Bird and Call (JA) 1998
[6] Bowman and Prior (2004)
[7] Mwangi, 2007.
[8] Homewood et al. (2001)
[9] DeFries et al (2007)

[10] We employ the term environmental rather than ecosystem services because the services in question involve outputs and processes that transcend the ecosystem per se and involve, at the largest scale, the earth system (e.g., climate) (see Daily 1997; MEA 2005). It is also noteworthy that while various research communities separate provisioning from cultural services, the distinction appears to be somewhat less one of their function in the coupled system but in their economic roles and scale. Both provision, but cultural services tend not serve material needs (e.g., recreation vs. food) and involve land or landscape scale features, such as sacred mountains.

[11] Lawrence

[12] E.g., Cohen (1995)

[13] Coleman and Schofield (1986)

[14] E.g., Cohen (1995). It is noteworthy that a true Malthusian crisis—one in which famine and malnutrition followed strictly within a coupled system in which the population surpassed the capacity of the society to provide food—is difficult to demonstrate. Dando (xx) noted that all famines are societal constructions. Sen (xx) formalized this idea in entitlement theory; famines and malnutrition follow from inadequate entitlements to food and resources by some segment of the population.

[15] Hayami and Rutaan (1985); Pingali, Bigot and Binswanger (1987); Turner and Ali (1996).

[16] Turner and Ali (1996)

[17] Ref needed

[18] Pielke et al. (1999)

[19] Liu (2007)

[20] Micklin (1988), Kasperson, Kasperson and Turner (1995)

[21] Hansen and Libecap (2004); Worster (1979)

[22] IGBP (1988)

[23] CIESIN (xx), Raynor et al. (1999), Berkes (2007), Meinzin-Dick (2007), Nagendra (2007)

[24] Auffhammer et al. (2006)

[25] Chameides et al 1994

[26] Liu et al. (2007)

[27] Koestler (1973)

[28] Steffen et al. (2004), PNAS-Schellnhuber

[29] Laurence (2007)

[30] Turner et al. (2003a,b); Matson xx;

[31] Hecht and Saatchi (2007)

[32] Progressive contextualization is a method of analysis proposed for human ecology by Vayda (1983) and subsequently for the human dimensions of global change by Dietz and Rosa (2002). The method begins with the immediate problem, following the trail of connections to it that enlarges the problem set while embedding the initial problem in that set.

[33] Pielke (2005)

[34] ???

[35] ref

[36] Brock and Carperter, 2007.

[37] Tucker, 2008

[38] Human Genetic Variation was declared by "breakthrough of the year 2007" by the editors of *Science*. "In 2007, researchers came to appreciate the extent to which our genomes differ from person to person and the implications of this variation for deciphering the genetics of complex diseases and personal traits." (Pennisi, 2007, 1842).

[39] Sterner (2007)

[40] Ostrom, 2006

[41] Brock and Carpenter, 2007

[42] Lenton et al. (2007)

[43] Brock and Carpenter, 2007.

[44] Tainter xx; Diamond xx; Micklin (1988)

[45] Liu et al. (2007), Turner et al. (2003b), Wilson, 2002, +

[46] Turner and Robbins (2008)

[47] Young et al. (2006), Turner et al. (2003a), Chapin et al. (2007). Also see special features of the *Proceedings of the National Academy of Sciences* (USA) such as that on panaceas in human-environment

relationships (Ostrom, Janssen and Anderies 2007) and land change science (Turner, Lambin and Reenberg 2007).

[48] Lambin and Geist (2006)

[49] Curran et al. (2004) ; Lambin et al. (2001) ; Luarance (2007)

[50] Steffen et al. (2004)

[51] It is noteworthy that technology can also serve as demand generating factor when major shifts in technology unveil resources or access to resources that did not exist previous to the shift (Grübler 1998). The global explosion in cell or mobile phones is a case in point.

[52] xx

[53] Tilman (1996)

[54] Rock and Angel (2005)

[55] Lee (1984)