

Coupled human and natural systems: The evolution and applications of an integrated framework

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Jianguo Liu, Thomas Dietz, Stephen R. Carpenter, William W. Taylor, Marina Alberti, Peter Deadman, Charles Redman, Alice Pell, Carl Folke, Zhiyun Ouyang, Jane Lubchenco

INTRODUCTION

In our paper “Coupled Human and Natural Systems” (Liu et al. 2007), we developed a timely, theoretical, and practical foundation for research on Coupled Human And Natural Systems (CHANS). The science of CHANS builds upon, but goes beyond previous research that linked humans and ecosystems (e.g., ecological anthropology, environmental geography, human ecology). CHANS science uses a holistic perspective to integrate patterns and processes that connect human and natural systems, as well as within-scale and cross-scale interactions and feedbacks between human and natural components of such systems (Fig. 1). Such an integrated framework is needed to understand the increased complexity of the Anthropocene and develop innovative solutions to unprecedented global challenges.

Over time, key ideas in this framework, in particular cross-scale interactions and feedbacks, also became incorporated into closely related concepts such as “social-ecological systems” and “human-environmental systems”. All three concepts are often used interchangeably, although formally the latter two are subsets of CHANS because CHANS includes not only social dimensions but also many other human dimensions (e.g., economic, cultural) that are not emphasized in the term of “social-ecological systems”. Similarly, the CHANS framework emphasizes consideration of all aspects of nature including not only environmental processes in the term of “human-environmental systems” but also other dimensions (e.g., hydrological, climatic). We emphasize that the communities that use these various concepts overlap and that the concepts involved are not in contradiction, but simply note that the term of CHANS tends to be the most encompassing. Since the publication of original CHANS ideas, research on CHANS

has grown dramatically. In this essay, we offer a brief overview of the impact of our paper and highlight how the paper has inspired some later work such as telecoupling (Liu et al. 2013) and metacoupling (Liu 2017).

IMPACT OVERVIEW

This paper has been cited in many languages, on a wide variety of topics, by scholars in many countries and from many disciplines, including ecology, land use, natural resource management, social sciences, and sustainability science. The paper's impact extends well beyond citations. Indeed, citation analysis underestimates impact. The CHANS paper was preceded by the Millennium Ecosystem Assessment¹ and crystallization of sustainability science and resilience concepts, for example, and the CHANS paper brought these ideas together and helped link these communities. As often happens in the history of science, frameworks like CHANS become generally accepted background knowledge that have influence without being cited. Similarly, many later publications adopted ideas from the CHANS paper without citing it. For instance, CHANS approaches are now widespread in global change science (e.g., Nyström et al. 2019). A key paper developing the link between CHANS and sustainability (Liu et al. 2015) was given the “Sustainability Science Award” by the Ecological Society of America.

The paper also catalyzed the establishment of the “International Network of Research on Coupled Human and Natural Systems” (CHANS-Net) to promote and facilitate communications and collaborations between a diverse

¹ <https://www.millenniumassessment.org/documents/document.356.aspx.pdf>.

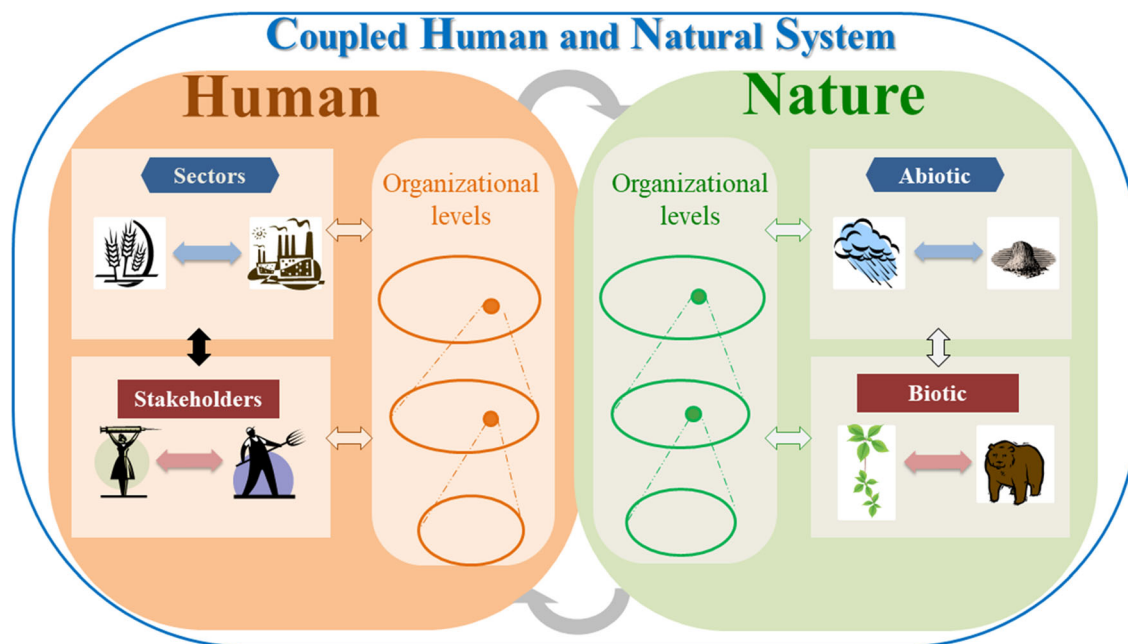


Fig. 1 A schematic diagram of a coupled human and natural system. Arrows show interactions and feedbacks. (courtesy of Vanessa Hull.)

community of CHANS scholars. CHANS-Net has organized several dozen workshops, symposia and other events at national and international scientific meetings. Many publications have resulted from these events (e.g., Kramer et al. 2017). CHANS-Net has also supported many young scholars (e.g., CHANS Fellows) from all over the globe to attend, present, network, collaborate, and learn from senior scholars at the various events.

The paper has important implications for conservation, management, and policy. For instance, it underpins the goal of achieving human-nature harmony. This idea has been endorsed by the Convention on Biological Diversity as the 2050 Vision “[Humans] Living in Harmony with Nature”. The CHANS perspective also has helped generate important information for transforming the dynamics of the habitat of a global wildlife icon—giant pandas—from long-term loss to gradual recovery (Liu et al. 2016). Subsequently, in 2016, the giant panda was removed from the endangered species list of the International Union for Conservation of Nature, IUCN (downgraded from endangered to vulnerable). Traditional research on giant pandas focused on panda biology, which is needed, but the critical force behind the panda’s endangerment was habitat loss due to human activities. As a result, even in the flagship nature reserve for panda conservation, the panda habitat was lost faster after the reserve’s establishment than before. CHANS research was able to illuminate how and why humans affected panda habitat, how changes in panda habitat prompted the Chinese government to develop new policies, how and why the new

policies altered human attitudes and behaviors, and how these feedback loops evolved over time and across space. The findings provided unique insights into diverse human needs, complex human-nature interactions, and win-win solutions for humans to prosper and pandas to thrive (Liu et al. 2016).

EXAMPLES OF APPLICATIONS

The CHANS framework has transformed the field of urban ecology and the conceptualization of urban ecosystems as complex systems of interacting social and ecological processes across multiple temporal and spatial scales (Alberti 2008). It inspired theoretical advances and research design of the two US Urban Long-Term Ecological Research sites, Phoenix and Baltimore (Pickett et al. 2020). Cities as coupled human natural systems are gaining a new attention in the study of rapid urban evolutionary change and urban eco-evolutionary dynamics (Alberti et al. 2020). Advances in urban ecology and eco-evolutionary dynamic provide fertile ground to extend the CHANS framework to incorporate both urban and evolutionary dynamics (Des Roches et al. 2020).

In rural settings, CHANS concepts have been used in a series of projects focused on evaluating water availability, use, and quality in Canadian agricultural watersheds (Liu et al. 2019). These projects focus on the key drivers, including hydro-climatic, geomorphic, agricultural land management practices, and watershed governance

frameworks. The work is accomplished through field-based research, data mining, and socioeconomic modeling. Agent-based models link human decisions related to agricultural best management practices to biophysical conditions in the watershed and regulatory programs and frameworks.

CHANS concepts and framework also have increased tractions in aquatic systems and at the interfaces between terrestrial and aquatic systems. For example, the CHANS framework provides new insights into restoration and governance of ocean ecosystems (Lubchenco and Petes 2010). Fisheries have been treated as CHANS to effectively study and manage them in a holistic manner (Lynch and Liu 2014). Studying floodplains as CHANS offers advantages (e.g., facilitating interdisciplinary collaborations and in-depth disciplinary analytical examination) over the use of several other frameworks (Moritz et al. 2016).

While the CHANS framework has been effective for bringing together those who focus on ecology, social sciences, and natural resource management and policy, expanded frameworks have been suggested to add more engineers, planners, and other “design” professionals into the mix (Redman and Miller 2015). The key insight has been to view infrastructure and technology as systems in themselves and that through their close “coupling” with human and natural systems can better understand and effectively intervene in the overall system. In studies of urban sustainability, this is exemplified by the social, ecological, and technological systems approach used by the Urban Resilience to Extremes Sustainability Research Network (Markoff et al. 2018) and many subsequent projects (Hobbie and Grimm 2020).

FROM COUPLED TO METACOUPLED HUMAN AND NATURAL SYSTEMS

Although the framework of CHANS has had considerable impact, most CHANS research has focused on a specific place or comparisons between a few different places. With globalization, external forces such as international trade are becoming increasingly powerful in shaping place-based human-nature interactions. For example, the world’s agricultural product exports across country boundaries jumped 45-fold during 1961–2018.² Interactions among CHANS are increasingly important and new frameworks are needed to account for such increasing importance of cross-boundary interactions.

To take interactions among distant CHANS into consideration, an umbrella concept—telecoupling (human-

nature interactions over distances, such as international trade, species invasion, tourism, and human migration)—was created in 2008. While the CHANS framework drew on the research traditions of many areas such as human ecology, social-ecological systems, and human-environmental systems, the concept of telecoupling substantially expanded the scope of the analysis and allowed links to traditions in the natural sciences (e.g., teleconnection in climate change and animal migration in ecology) and social sciences (e.g., trade in economics, world systems theory in sociology) that emphasized actions at a distance across the world. The framework of telecoupled human and natural systems was developed to facilitate quantitative analyses of such linkages (Fig. 2).

The integration of socioeconomic and environmental interactions is a major difference between the telecoupling framework and previous frameworks of distant processes such as animal migration or human migration. Traditionally, frameworks of animal migration largely focused on biological aspects, while frameworks of human migration mainly focused on socioeconomic dimensions. Some work in the social sciences, in particular environmental world systems theory, also incorporate both ecological and social systems, but mostly see the latter as driving the former (Jorgenson 2016). The telecoupling framework incorporates the insights on trade and the global political economy from this tradition, but expands upon them by emphasizing multiple links and feedbacks. Use of the telecoupling framework can help identify knowledge gaps and reveal “invisible” and unexpected impacts. For instance, negative spillover effects on Brazil’s *Cerrado* (a global savannah biodiversity hotspot) offset conservation efforts in the Amazon (Dou et al. 2018). More specifically, the supply chain agreements (Soy Moratorium and zero-deforestation beef agreement) protected much of the Amazon forest from being converted from native land to food production but pushed food production to the *Cerrado* region and resulted in a substantial increase of deforestation there (Dou et al. 2018).

Using the telecoupling framework can address many fundamental questions, e.g., how do telecouplings compromise or enhance environmental sustainability and human well-being in sending, receiving, and spillover systems? How do telecouplings amplify or offset other forces behind environmental sustainability and human well-being? How can spillover systems be better detected and accounted for in policy? Addressing these and other related questions requires the incorporation of methods and insights from a variety of disciplines such as ecology, economics, behavioral sciences, geography, sociology, information and sensing technologies, and policy science. Telecoupling is designated as a research priority by the Global Land Programme and featured in authoritative

² <http://comtrade.un.org/db>.

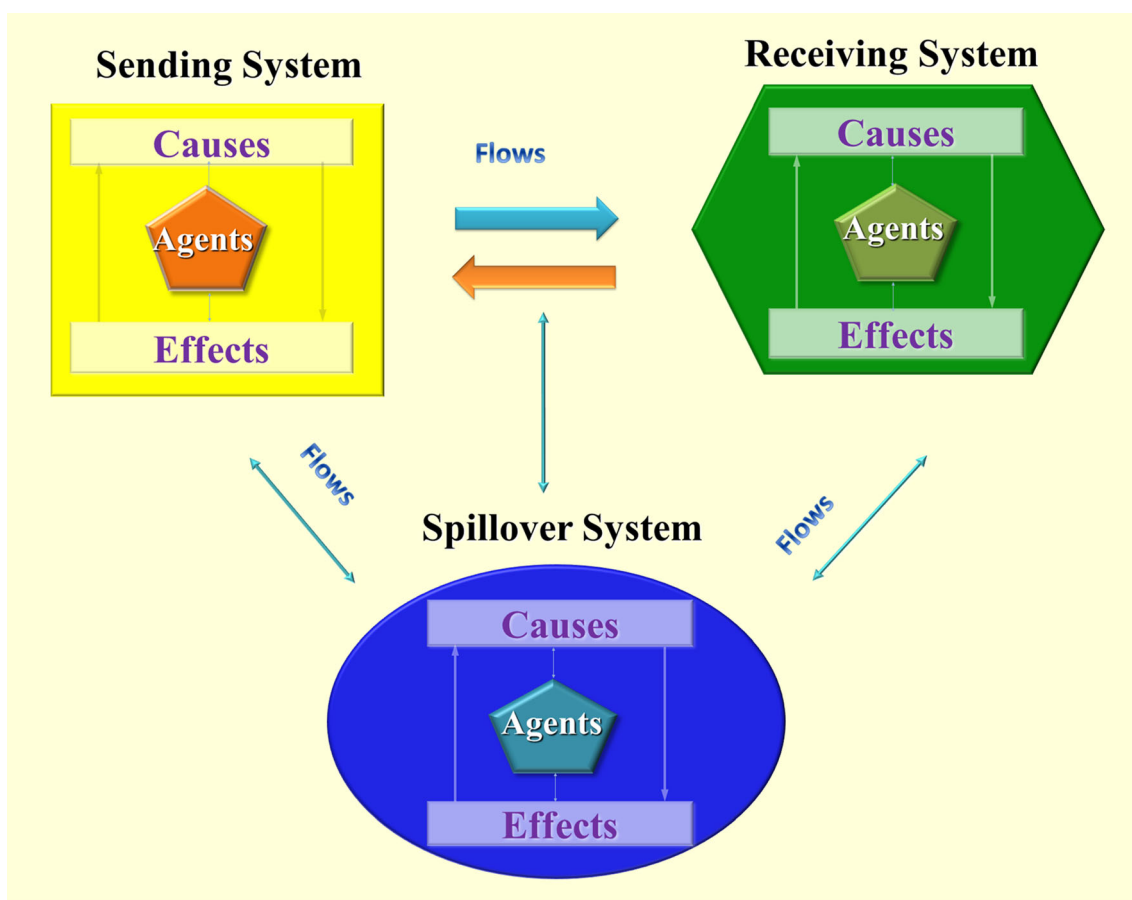


Fig. 2 Five major and interrelated components of the telecoupling framework. A telecoupled system consists of interacting coupled human and natural systems through flows. Each coupled system includes three interrelated components: causes, effects, and agents. Causes are reasons behind the flows, effects are consequences of the flows, and agents are decision-making entities that facilitate or hinder the flows. A system can be sending, receiving, and/or spillover systems, depending on the direction of a flow. For the sake of simplicity, local couplings within a coupled system are not shown. (from Liu et al. 2013)

reports such as the Global Assessment of Biodiversity and Ecosystem Assessment (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services³) and Global Environment Outlook.⁴ It has been highlighted in the news outlets such as *Time* magazine⁵ and by high-level officials of the United Nations.⁶ Additionally, a number of funding agencies support telecoupling research and education. For example, the European Union has been supporting a PhD program on telecoupling (“COUPLED-Operationalising Telecouplings for Solving Sustainability

Challenges for Land Use”,⁷ with 15 PhD students in its first cohort across Europe).

To capture interactions within and among adjacent and distant CHANS, a new integrated framework of metacoupling (human-nature interactions within as well as between adjacent and distant systems) has been developed (Liu 2017). The metacoupling framework consists of the coupled human and natural system framework (intracoupling—human-nature interactions within boundaries), the telecoupling framework, the framework of pericoupling (human-nature interactions between adjacent systems), and the interrelationships among intracoupling, telecoupling, and pericoupling (Fig. 3). The metacoupling framework is useful to develop realistic understanding of the complexity of real-world phenomena. For example, the framework is successfully applied to global marine fishing (Carlson et al. 2020), which occurs within exclusive economic zones

³ https://ipbes.net/sites/default/files/inline/files/ipbes_global_assessment_report_summary_for_policymakers.pdf.

⁴ <https://www.unenvironment.org/resources/global-environment-outlook-6>.

⁵ <https://science.time.com/2011/02/23/the-new-science-of-telecoupling-shows-just-how-connected-the-world-is%E2%80%9494for-better-and-for-worse>.

⁶ <https://news.trust.org/item/20190617080047-bv0jq>.

⁷ <http://coupled-itn.eu/>.

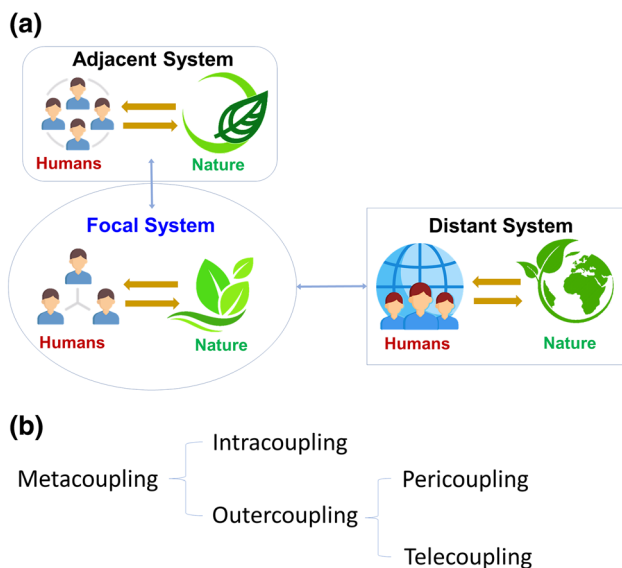


Fig. 3 **a** A schematic diagram illustrating a focal coupled human and natural system, an adjacent system, and a distant system, as well as their interactions (indicated by arrows) (modified from Liu 2017 and courtesy of Shuxin Li). **b** Metacoupling consists of intracoupling and intercoupling, which in turn includes pericoupling and telecoupling (from Liu 2017)

(EEZs, intracoupling), between adjacent EEZs (pericoupling), and between distant EEZs (telecoupling). The framework has also been used to evaluate impacts on the UN Sustainable Development Goals (SDGs) and targets because human activity in one place can affect the progress toward SDG targets elsewhere through trade and other metacouplings (Xu et al. 2020). The application of the metacoupling framework in nexus approaches for global sustainable development has been given the “Innovations in Sustainability Science Award” by the Ecological Society of America.⁸ The CHANS and expanded frameworks are tools suitable for analyzing and understanding various human-nature nexuses across space.

PERSPECTIVES

The initial spirit of CHANS—to provide an integrated framework while incorporating insights from a diversity of research traditions—remains. The ongoing COVID-19 pandemic is an obvious example—understanding requires examining the links between human and natural systems and understanding linkages that span the globe, but that manifest in local places as well as regionally and globally. COVID-19 is a global perturbation experiment on meta-coupled systems. It has unprecedented impacts on human

health, economy, transportation, markets, medical supplies, food distribution, and so on, and these impacts are inequitably distributed across and within nations. On the other hand, this is a unique learning opportunity. As the impacts from the COVID-19 episode continue to unfold, the CHANS community should seize the opportunity to learn what a hard, sharp shock does to a complex system.

The interrelated and daunting challenges that the world now is grappling with, including the COVID-19 pandemic, climate change, dysfunctional food distribution, and social inequality and injustices, require integrated approaches that are core to CHANS and expanded frameworks. Continuing exploration and expansion of the many insights highlighted in the initial CHANS paper can help the world better understand and address crucial societal and environmental challenges.

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⁸ https://esa.org/history/sustainability-science-award-2/#tablepress-3-no-2_wrapper.

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- Thomas Dietz**
Address: Department of Fisheries and Wildlife, Center for Systems Integration and Sustainability, Michigan State University, East Lansing, MI, USA.
Address: Department of Sociology & Environmental Science and Policy Program, Michigan State University, East Lansing, MI, USA.
- Stephen R. Carpenter**
Address: Center for Limnology, University of Wisconsin, Madison, WI, USA.
- William W. Taylor**
Address: Department of Fisheries and Wildlife, Center for Systems Integration and Sustainability, Michigan State University, East Lansing, MI, USA.
- Marina Alberti**
Address: Department of Urban Design and Planning, University of Washington, Seattle, WA, USA.
- Peter Deadman**
Address: Department of Geography and Environmental Management, University of Waterloo, Waterloo, Canada.
- Charles Redman**
Address: School of Sustainability, Arizona State University, Tempe, AZ, USA.
- Alice Pell**
Address: College of Agriculture and Life Sciences & College of Veterinary Medicine, Cornell University, Ithaca, NY, USA.
- Carl Folke**
Address: Beijer Institute of Ecological Economics, Royal Swedish Academy of Sciences, Stockholm, Sweden.
Address: Stockholm Resilience Centre, Stockholm University, Stockholm, Sweden.
- Zhiyun Ouyang**
Address: Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, Beijing, China.
- Jane Lubchenco**
Address: Department of Integrative Biology, Oregon State University, Corvallis, OR, USA.

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Jianguo Liu (✉)

Address: Department of Fisheries and Wildlife, Center for Systems Integration and Sustainability, Michigan State University, East Lansing, MI, USA.
e-mail: liuji@msu.edu