Pardee School of Global Studies
The Frederick S. Pardee Center for the Study of the Longer-Range Future

039

AUGUST 2020

ISSUES IN BRIEF

New Perspectives on the Dynamics of Coupled Human and Natural Systems (CHANS)

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Emily S. Klein and Les Kaufman

Over a decade ago, prominent sustainability scholar Jianguo Liu and colleagues introduced the term *"coupled human and natural systems"* (Liu et al., 2007), or CHANS. These authors argued that we had yet to fully address or appreciate the interconnectivity of people and nature, and the resulting complexity of our world, despite decades of study. They attributed this deficiency to the distance between the natural and social sciences, a lack of empirical evidence for scientific theory, and a failure to apply what little theory existed. To remedy this, Liu and his colleagues called for work that explicitly delves into the interactions and feedbacks between human communities and the natural systems we rely on, using integrated tools, techniques, and concepts from across natural and social fields of study, and working towards a unified complex systems science. The authors also recommended organizing case studies into "coordinated, long-term comparative projects" to reveal general principles, deepen our understanding of CHANS, and ultimately improve humanity's prospects for the future.

Prior to and in the years since Liu's and colleagues' seminal paper, work employing terms similar to CHANS has also increased in popularity, such as *"social- or socio-ecological systems"* or *"human-environmental systems."* Studies using these terms may differ in subtle ways from CHANS (Kramer et al., 2017), but research under all these umbrellas strives to holistically understand the deeply embedded relationships between nature and people existing in the same environment, an environment profoundly shaped by human activities. How are the social, cultural, economic, and political systems of people connected to our natural world? What broad lessons can we learn to better understand the present — and plan for a future of vibrant human societies *and* ecological communities in a changing climate? Can we use that knowledge to make wise decisions on food and water security, climate change mitigation, and biodiversity preservation?

The CHANS program at Boston University's Frederick S. Pardee Center for the Study of the Longer-Range Future has aspired to address Liu's call to action, combining observation, experiment, modeling, and theory to advance CHANS science while providing useful, applied outcomes for people. Over the past decade and around the globe, we have helped demonstrate how the CHANS approach of combining the natural and social sciences can help us understand today and plan for tomorrow.

Putting CHANS to work

The Pardee Center's program embodies best practices in CHANS research and is unique in two ways:

(1) our approach of integrating field research with systems modeling, scenario exploration, and community engagement; and
(2) the application of this approach to CHANS in multiple sites around the globe for both local understanding and comparative assessment.

Together, these two aspects set our CHANS work apart and ensures we meet the foundational call of Liu and colleagues (2007).

Our integrated approach

To study CHANS, we first focus on linking research and observations with **systems modeling,** i.e. we engage in field research, often with local partners, and connect that with existing and expert knowledge via the *Multiscale Integrated Model for Ecosystem Services* (MIMES; Boumans et al., 2015), a framework that allows us to build dynamic computer models of specific places. Using MIMES, we construct and investigate connections among people, ecosystems, and the environment — and how these connections change over time — to reveal collective outcomes and realistic trade-offs (Altman et al., 2014; Boumans et al., 2015; Willemen et al., 2019). For example, with MIMES we may model the annual flood cycles of a particular river basin to capture the potential ecological benefits (e.g., replenishment of soils in agricultural areas), the potential risks to people living in the basin (e.g., damage to homes and infrastructure, loss of livelihoods), and how cycles and risks evolve or may be impacted by what people choose to do. Moreover, accurately representing both nature and the economic, social, and cultural human systems in MIMES necessitates information from across disciplines and sources, and MIMES is explicitly built to accommodate a range of data and the input of experts from many fields. Through systems modeling using MIMES, we provide insight into the dynamics and function of CHANS as well as the potential impacts of human decisions and changing environmental conditions, providing a valuable foundation for sound policy (e.g. Fulton et al., 2015).

To use our systems modeling for **scenario exploration,** we next employ MIMES as a 'virtual laboratory' to explore possible future scenarios in a holistic, systems-centered manner (Willemen et al., 2019). In this way, MIMES operates much as a flight simulator allows an airplane pilot to practice and train — only with MIMES we explore how coupled systems work and evolve into possible futures, and, importantly, ask *what if* questions. For example, in our modeled river basin, we can ask important questions about the future: *What if* climate change means more intense floods of longer duration, or *what if* people adopt various adaptation or mitigation strategies (i.e., planting different types of vegetation to buffer floods, relocating homes and critical infrastructure outside of the flood zone, etc.)? We employ such scenario exploration not to predict exact outcomes, but to derive a range of likely alternative pathways for both a changing world and differing human decisions. This is akin to the scenario methods used by the Intergovernmental Panel for Climate Change (IPCC) and by many groups in the 2020 novel coronavirus pandemic, wherein numerous models and scenarios provide an array of possible actions amidst changing conditions, allowing people to make more informed decisions.

Finally, it is critical we communicate our CHANS work and results to diverse communities and stakeholders (Altman et al., 2014), which we do through **participatory modeling** via the *Modeling Integrated Decision Analysis System* (MIDAS; Gopal et al., 2015). MIDAS allows us to present outcomes from our field research, systems modeling, and scenario exploration in a visual and accessible way. A user-friendly, web-based interactive platform, MIDAS allows the people and communities we work with to readily visualize potential futures by more clearly perceiving outcomes of their decisions and potential tradeoffs of different choices under changing conditions. It helps convey a shared vision, but can also show how visions diverge, and how differing objectives and resulting decisions can lead to alternative outcomes.

Our First Four: Comparative analysis of CHANS dynamics

The CHANS program is further unique because of our comparative and coordinated study of multiple locations around the world. We focus primarily on four coastal ecosystems, two freshwater and two marine. Our freshwater systems are the Mekong Basin, focused on the Tonle Sap and Mekong Delta in Cambodia, and the Nile Basin, centering on the Lake Victoria Region in East Africa. For the oceans, we chose the Northeast seaboard of the US, specifically the southern Gulf of Maine, and the tropical West Atlantic and Caribbean Basin, particularly South Florida and Belize. Through this system of comparative studies, we work to be locally relevant while also advancing CHANS science more broadly. In each study area, we partner with local people, including fishers, farmers, in-country scientific colleagues, and government and community leaders, to forward local understanding and to put that understanding to work for on-the-ground needs. At the same time, by using the common approach discussed above in all areas, we can look *across* the four systems for broad patterns and to build general CHANS theory.

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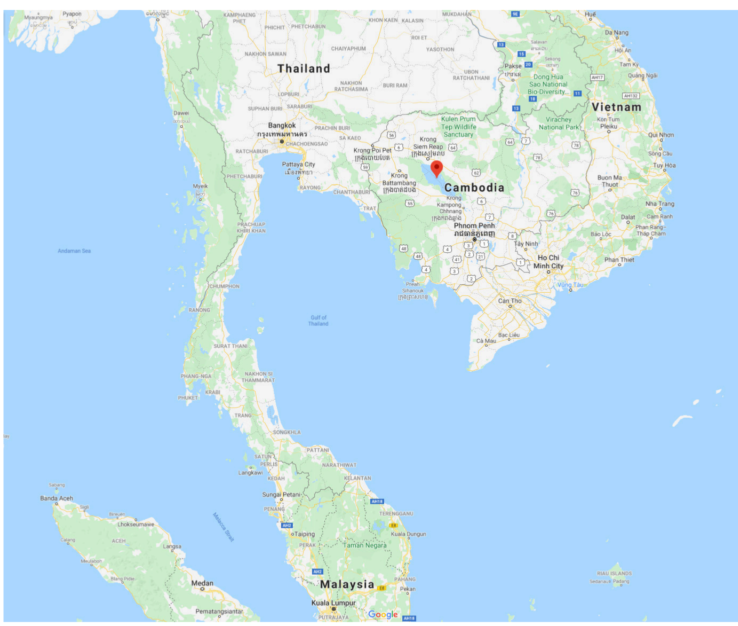
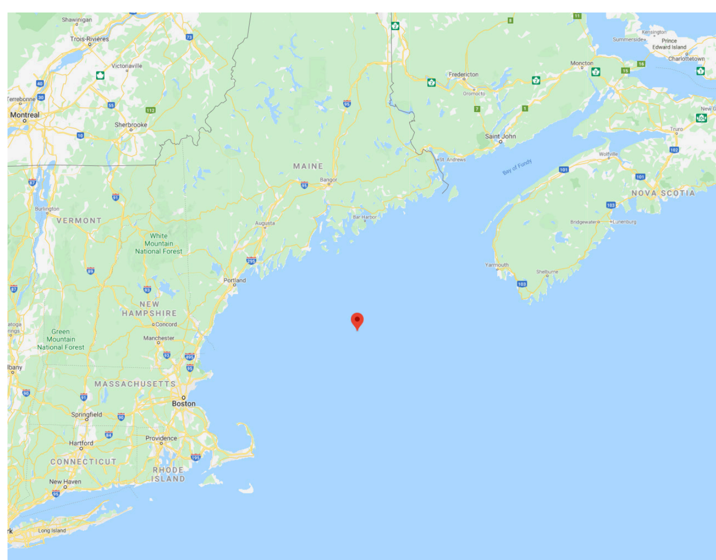


Our first freshwater system, **the Mekong River and its great lake, Tonle Sap,** supports one of the world's two largest inland fisheries (the other one is Lake Victoria) as well as a biodiversity hotspot. Our work in the Lower Mekong Basin of Cambodia began in 2012, where we focused on the ramifying outcomes of a single major human impact, hydroelectric dams. Dams are a major concern for many of the world's great waterways, but most especially along the Mekong, where original plans called for more than 200. Several are meant to generate electricity and nourish crops, yet these also obstruct fish migrations, dooming or greatly reducing populations of commercially and ecologically essential species. Our field work and modeling further revealed a troubling synergy between climate change impacts on water flow, and the effects of the dams. The scenarios we projected, including extreme low water in the Lower Mekong, poor fish yields, and a host of other detrimental impacts on the daily life of people, have since come to pass. While it is frustrating that our insights could not be used to effect preventive measures, such outcomes were only uncovered by looking forward through a CHANS lens.

Lake Victoria, our second freshwater site, is the largest tropical lake in surface area in the world and also a freshwater biodiversity hotspot that supports the world's other most important inland fishery. Its shoreline is home to densely populated human communities highly dependent upon the lake's freshwater resources for food and livelihoods. Our CHANS work in Lake Victoria began in 2014, and built upon continuous field, laboratory, and remote sensing studies first launched in 1989. In the 1980s, the interacting effects of cultural eutrophication, the introduction of exotic fish species (Nile perch and Nile tilapia), and climate change precipitated a mass extinction of perhaps half the lake's estimated 500 endemic species of fishes. In recent years, the introduced species have been overfished, triggering see-saw dynamics in this still highly unstable yet curiously resilient system (e.g. Downing et al., 2014). Meanwhile, cage aquaculture of Nile tilapia has rapidly expanded in Kenyan and Ugandan waters, posing additional opportunities and threats (Hamilton et al. 2020). In contrast to our work in the Lower Mekong that denoted expanding consequences of a single human impact, our work in Lake Victoria focuses on these interacting stressors and ongoing change. Now, armed with three years of rich, new data on the lake as an integrated and integral system, we are exploring the interplay of watershed and fisheries management, limnology, and climate change, and the ebb and flow of Lake Victoria's endemic fish species.

Our marine study areas — one temperate, one tropical — have been most revealing of challenges inherent in *tradeoffs* among human needs. In **the Gulf of Maine,** *forage fishes* (those that other species rely on for food) are the prey base for important commercial fisheries as well as the lucrative whalewatching industry, and are themselves targets in *reduction fisheries* (fisheries supplying raw materials for food additives, pharmaceuticals, and other products instead of being eaten by people). Despite mutual dependence on the same species, these sectors are managed as if they operate in separate universes. Our CHANS work here started in 2010, based on 20 years' worth of field work and direct involvement in marine management. Results uncovered several ways that isolating fisheries sectors can be problematic. For example, we found that, due to the



Box 1. Best practices in CHANS research

1 The right tools

We must be able to account for moving pieces in CHANS (e.g. variability in annual rainfall as well as in human demand for a product) — and the way they behave and interact. Thus tools for CHANS research must fundamentally incorporate relationships and feedbacks, engage resources from across disciplines, and ensure what is learned can be applied to support wise decisions now and in the future.

2 Interdisciplinary perspectives

Studying CHANS requires incorporating elements of both the natural and social sciences through various collaborations with other scholars as well as experts from the non-profit and private sectors and partners in local communities.

3 Engagement and participation

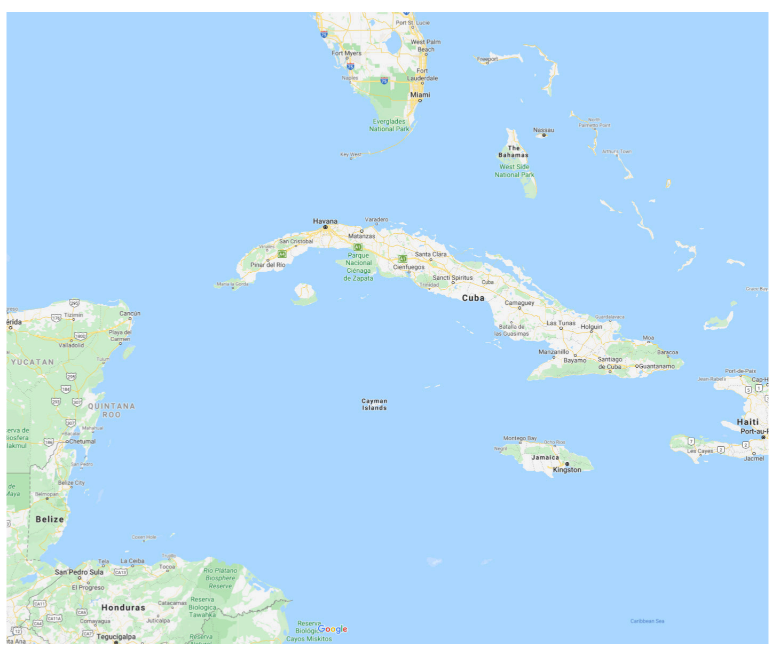
Ensuring cutting-edge CHANS research is also valuable for solving on-the-ground problems is further supported by building and validating models in partnership with a wide array of stakeholders, creating a problem-solving community that discusses goals and outcomes needed from across scientific and community perspectives. Such engagement can refine key research questions and ensures direct relevance to current and future needs.

4 Comparative approach

For research to be both locally relevant and advance the field of CHANS more generally, an overarching approach and strategy should be determined ahead of time, which can then be applied consistently to multiple locations.

foraging behavior of humpback whales, balancing the whalewatching and fishing industries will require limits to fishery catch that are a fraction of what is currently projected based on study of the fishery alone. Current work is now looking at interactions of sand mining for beach re-nourishment — an increasing need with more frequent and stronger coastal storms — which uses the same sand habitats important for these forage fish, denoting another currently invisible dependency on them. We are uncovering emergent interacting impacts as well as the ways sand mining could operate to offset both ecological risks and indirect consequences for other sectors.

In our tropical marine study area, CHANS-related modeling studies in the **greater Caribbean** started in 2008, beginning in Belize, and later switching focus to South Florida. We have embarked on empirical studies here since 1974, and most recently we have been exploring



the ecological economics of Florida's coral reef. Devastated by overdevelopment, overuse, and climate change, coral reef habitat is nonetheless a lynchpin of South Florida's economy, culture, and way of life. Related tradeoffs are acute: for example, the death of coral reefs threatens all human interests from real estate to biodiversity conservation, yet it is extremely challenging to propose habitat or reef protection or restoration efforts that put even the smallest areas off limits to fishing. We are examining the interacting dynamics of disparate sectors rarely considered together: the hydrology of the Everglades, commercial and recreational fisheries, tourism and coastal real estate, endangered species, coral reef health, and sea level rise. In leveraging our CHANS approach, we aim to find solutions to such wicked and pressing problems that can prove effective and reliable over the long term.

Lessons learned

After our decade of CHANS research around the world, we have learned several key lessons. First, our findings are fundamentally the result of shifting to a dynamic, systems approach (Box 1). Results and recommendations were only possible with a CHANS perspective that truly linked people and the natural world, engaged across communities for real-world understanding and buy-in, and provided the ability to look forward across multiple possible futures.

Second, our years of comparative research demonstrated commonalities in system processes across locations. This is very useful from a practical standpoint, as it means model components representing these common processes (such as predator-prey dynamics or watershed runoff) can be employed in other locations. We can therefore be nimble in building complex systems models and exploring future scenarios in new geographies (Boumans et al. 2015), a particularly valuable ability because, although models like those we develop are increasingly used both in basic science and in support of management decisions (e.g. Fulton et al., 2015), they can take a large amount of time and effort to build. Further, transferring and utilizing common information in multiple locations allows us to develop and test related CHANS hypotheses (Altman et al 2014).

Our work also clarified a crucial and unifying thread across locations: the reality of our uncertain future. For example, climate change is increasing uncertainty about tomorrow for all areas and across all societies. We have found that, in the face of climate change and other major events such as the current and future pandemics, people will need to adjust their economic goals and recognize that ecosystem goods and services will change (e.g. Dobson et al., 2020). We have found such adjustments hard to see and even more challenging to solve without a CHANS lens. In addition, we have uncovered some systems currently highly productive in the ecosystem goods and services that support human well-being may also be 'brittle': they are only productive under a limited range of conditions and may not maintain ecosystem service flows while adapting to new and uncertain conditions — a dynamic potentially exacerbated by climate change. Moreover, people in systems that are currently providing well for them may be less motivated to alter their goals or behavior, or to acknowledge coming change even when its likelihood is made plain. Therefore, high productivity may mask the fact that these systems — and the people living in them — are very vulnerable to the high uncertainty and rapid changes that characterize our current world.

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Yet, our research shows a constructive way forward amidst this uncertainty. First, our CHANS approach of scenario exploration and participatory modeling builds adaptability into the decision-making process and can, in turn, instill confidence *despite* uncertainty, as different scenarios incorporate a number of varying outcomes instead of a limited few. This process can help people envision their options and see a path forward, offering clarity on how they might alter behavior, motivations, and values by following differing options through to potential results and new opportunities. Second, this process can highlight brittle systems by actively exploring possible futures that help make current vulnerabilities more concrete, while also showing alternative ways forward and new possible benefits. Finally, however, our work also reveals people's ability to adapt can be strongly bounded by their current circumstances, such as living below the poverty line or in food deserts. Even when people want to change, socioeconomic drivers can severely limit their options, alerting us to ways the most vulnerable can easily be left behind.

Future directions: Advancing CHANS research

Building on our work over the past decade, the CHANS program at the Pardee Center is actively advancing the next frontier of CHANS science. We will continue our work in our four case study locations, looking across our findings for additional lessons learned and empirical evidence to further support CHANS theory more broadly. This involves synthesizing results across research sites to understand general patterns of dynamics, interactions, and change.

We are also more deeply revealing CHANS as (1) *connected,* (2) *changing,* and (3) *complex.*

- To the first, we are engaging new research to better understand how the social and cultural systems of human communities are connected to economic ones, the natural world, and the environment. For example, we are investigating the importance and role of social norms in human behavior and decision making, and how they impact and are influenced by ecosystems and the environment.
- Second, we are advancing knowledge of how CHANS change over time, specifically how people respond to both sudden, extreme events as well as gradual change, and what can be learned to guide future governance and increase community resilience.
- Finally, we are employing new tools to explore complex dynamics — including nonlinearity and chaos — that are ubiquitous in CHANS (e.g. Sugihara, 2010) but thus far rarely addressed in research, let alone our policies on natural resource use. For this, we aim for nothing less than a new paradigm in how we assess and manage humanity's relationships with natural systems, by employing new methods that leverage and benefit from their complexity rather than being confounded by it.

Conclusion: Towards a resilient future

While the term *coupled human and natural systems* can imply a distinction between people and nature, it is instead meant to remind us of our world's innate interconnectedness. Our past decade of studying CHANS has shown us best practices, illuminated specific systems and broad lessons, and provided operational outcomes for wise governance on the ground. In our next decade, we aim to build on this work, expanding our focus to advance approaches and our understanding, deepening our knowledge of people, change, and complexity, and forwarding the unified field of CHANS science.

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