2

What Is Telecoupling?

Jianguo Liu, Anna Herzberger, Kelly Kapsar, Andrew K. Carlson, and Thomas Connor

1 Introduction

Human and natural systems around the world are becoming increasingly connected through distant processes, such as international trade, migration, foreign investment, flows of ecosystem services, and species invasion. The speed, scale, complexity, and consequences of these interactions have profound implications for global challenges such as biodiversity conservation, food security, energy security, water security, environmental protection, and human well-being. For instance, biofuel policies in the USA and Europe catalyse land-use change that has socioeconomic and environmental impacts in distant areas worldwide (Liu et al. 2013). The complex impacts of these distant human-nature interactions demonstrate the need for an umbrella concept that can describe various distant interactions, and an integrated framework for systematic analysis to

J. Liu (✉) • A. Herzberger • K. Kapsar • A. K. Carlson • T. Connor
Department of Fisheries and Wildlife, Center for Systems Integration and Sustainability, Michigan State University, East Lansing, MI, USA
e-mail: liuji@msu.edu; herzber5@msu.edu; carls422@msu.edu; connort2@msu.edu

C. Friis, J. Ø. Nielsen (eds.), *Telecoupling*, Palgrave Studies in Natural Resource Management, https://doi.org/10.1007/978-3-030-11105-2_2

address the United Nations' Sustainable Development Goals and other global challenges.

The telecoupling concept and framework (Liu et al. 2013) are well-suited to understand the interconnected world and help map possible pathways towards desired goals. The concept of telecoupling refers to socioeconomic and environmental interactions over distances. The telecoupling framework was developed to provide a systematic, integrative method to evaluate telecouplings (Liu et al. 2013).

The goal of this chapter is to describe telecoupling—both the concept and the framework—with particular emphasis on telecoupled land-use change. We explain what the telecoupling framework is and address some frequently asked questions with example applications that illustrate the framework's utility for systematically understanding, managing, and sustaining telecoupled land use. We conclude the chapter by describing ongoing efforts to operationalise the telecoupling framework, apply it to telecoupled governance, and supplement it with an extended framework (i.e. metacoupling; Liu 2017) that is applicable across local to global scales.

2 Telecoupling Concept

The telecoupling concept was developed by integrating relevant disciplinary concepts such as teleconnections (interactions between distant climatic systems; Wallace and Gutzler 1981) and globalisation (interactions between distant human systems; Sassen 1999). Teleconnections and globalisation have been applied by land system scientists (Young et al. 2006; Haberl et al. 2009; Seto et al. 2012), but the telecoupling concept is more appropriate for land system research for several reasons. First, it avoids the confusion with the original meaning of those disciplinary concepts. Second, telecoupling emphasises feedbacks between distant systems, which are common among land systems. Third, it is a natural extension of concepts in land systems science that incorporates coupled systems, such as coupled human and natural systems, coupled social-ecological systems, and coupled human-environmental systems. Fourth, it connects various distant socioeconomic and environmental interactions, as well as their impacts. For example, studies on human migration and animal migration often focus on socioeconomic and ecological dimensions, respectively. However, in reality, human migration has ecological implications and animal migration has socioeconomic implications. Human migrants consume resources in destinations and emit pollutants, thus affecting the environment. Animal migrants, such as locusts, have enormous economic impacts because they predate crops along migration routes and in destinations. By including ecological dimensions in human migration research and socioeconomic dimensions in animal migration research, both human and animal migration can be treated as telecoupling processes. Similarly, other distant interactions can also be treated as telecouplings, such as international trade, foreign investment, water transfer, transnational land tenure transfer, species invasion, knowledge transfer, technology transfer, tourism, payments for ecosystem services, species dispersal, and atmospheric circulation (Liu et al. 2013). In other words, telecoupling is an umbrella concept that encompasses various distant interactions. It enables researchers to explore interrelationships among various distant interactions and feedbacks across multiple scales. It also captures the complexity of increasingly prevalent distant environmental and socioeconomic interactions, as well as their diverse drivers and effects.

The telecoupling concept was first proposed by the lead author in 2008, and the first symposium to discuss telecoupling was held at the 2011 annual meeting of the American Association for the Advancement of Science (AAAS; Table 2.1). Telecoupling was later chosen as a preferred concept by a group of land system scientists from around the world after long discussion at the Strüngmann Forum on "Rethinking Global Land Use in an Urban Era" held in Germany in 2012 (Eakin et al. 2014; Seto and Reenberg 2014). It was specifically recognised for its extension of teleconnections by explicitly considering socioeconomic and environmental interactions as well as feedbacks between systems. It was also noted for its comprehensiveness through its inclusion of distant interactions within a country or region rather than solely at the global scale implied in globalisation.

Table 2.1 Telecoupling events (examples)

Event name	Date	Location	Organisers
Telecoupling for Sustainable Development and Conservation Across Local to Global Scales (symposium)	April 9, 2018	United States Chapter of the International Association of Landscape Ecology, Annual Meeting, Chicago, IL, USA	Jianguo Liu, Yue Dou, Kelly Kapsar, Hongbo Yang
Telecoupling Framework: Concepts, Applications and Hands-On Exercises with the New Cloud-Based Telecoupling Toolbox (workshop)	April 10, 2018	United States Chapter of the International Association of Landscape Ecology, Annual Meeting, Chicago, IL, USA	Jianguo Liu, Francesco Tonini, Paul McCord, Min Gon Chung
Telecoupled Human and Natural Systems: Theory and Application to the International Food Trade (oral session)	June 8, 2017	Center for Global Trade Analysis, Purdue University's (GTAP) "20th Annual Conference on Global Economic Analysis", West Lafayette, IN, USA	Farzad Taheripour, Jianguo Liu
Telecoupling People and Landscapes among Distant Places around the World (symposium)	April 10, 2017	United States Chapter of the International Association of Landscape Ecology Annual Meeting, Baltimore, MD, USA	Jianguo Liu, Anna Herzberger, Jing Sun

(*continued*)

Table 2.1 (continued)

Event name	Date	Location	Organisers
Applications of the Telecoupling Framework and Hands-on Exercises with the Telecoupling Toolbox (workshop)	April 9, 2017	United States Chapter of the International Association of Landscape Ecology Annual Meeting, Baltimore, MD, USA	Jianguo Liu, Francesco Tonini, Yue Dou, Hongbo Yang
Telecoupling Framework as an Integrated Platform to Capture, Study, and Manage Complexity in a Changing World (poster session)	December 15, 2016	American Geophysical Union Fall Meeting, San Francisco, CA, USA	Falk Huettmann, Jianguo Liu
Exploring Mismatches and Power Asymmetries in Telecoupled Land Systems (oral session)	October 27, 2016	Global Land Project, 3rd Open Science Meeting, Beijing, China	Cecilie Friis
Untangling the Complexity of Telecouplings and Global Land System Change: Challenges and Opportunities for Bridging Geographic and Disciplinary Boundaries (forum)	October 27, 2016	Global Land Project, 3rd Open Science Meeting, Beijing, China	Jianguo Liu, Thomas Hertel
Land Systems in an Urbanising and Telecoupled World (poster session)	October 26, 2016	Global Land Project, 3rd Open Science Meeting, Beijing, China	Meeting organisers
Northern Eurasia in a Telecoupled World: Agricultural Potentials and Ecosystem Trade-offs (oral session)	October 26, 2016	Global Land Project, 3rd Open Science Meeting, Beijing, China	Alexander V. Prishchepov, Christian Levers, Florian Schierhorn

(*continued*)

Table 2.1 (continued)

Event name	Date	Location	Organisers
Urbanisation and Agricultural Land Use: Empirical Evidence, Models, and Policy Implications of Telecoupling (oral session)	October 26, 2016	Global Land Project, 3rd Open Science Meeting, Beijing, China	Daniel G. Brown, Qing Tian
Telecoupling Framework for the Global Land System Science Community (oral session)	October 25, 2016	Global Land Project, 3rd Open Science Meeting, Beijing, China	Jianguo Liu, Anna Herzberger, Emilio Moran, Peter Verburg
Interactions Between Food Security and Land Use in the Context of Global Change: the Belmont Forum Perspective (oral session)	October 25, 2016	Global Land Project, 3rd Open Science Meeting, Beijing, China	Reynaldo Luiz Victoria, William McConnell
Landscape networks as telecoupled human and natural systems (symposium)	April 4, 2016	United States Chapter of the International Association of Landscape Ecology Annual Meeting, Asheville, NC, USA	Jianguo Liu, Vanessa Hull
Telecoupling Framework for the Landscape Ecology Community (workshop)	April 3, 2016	United States Chapter of the International Association of Landscape Ecology, Annual Meeting, Asheville, NC, USA	Jianguo Liu, Vanessa Hull
Telecoupling Systems (satellite session)	October 1, 2015	European Conference on Complex Systems, Temple, AZ, USA	Beth Tellman, Jesse Sayles, Ashwina Mahanti, Karina Benessiah

(*continued*)

Table 2.1 (continued)

Event name	Date	Location	Organisers
Telecoupling framework for Studying Cross-border and Cross-scale Interactions (workshop)	July 5, 2015	International Association for Landscape Ecology, World Congress, Portland, OR, USA	Jianguo Liu, Vanessa Hull
Towards operationalisation of telecoupling concepts for land system science (workshop)	December 1–3, 2014	Global Land Project, Aeschi, Switzerland	Andreas Heinimann, Ricardo Grau, Ole Mertz, Ignacio Gasparri, Peter Verburg
Land Systems in a Telecoupled World	March 19–21, 2014	2014 Global Land Project, Open Science Meeting, Berlin, Germany	Patrick Hostert, Peter Verburg
Ecological Sustainability in a Telecoupled World (symposium)	August 8, 2013	Ecological Society of America, Annual Meeting, Minneapolis, MN, USA	Jianguo Liu, Harold Mooney
Ernst Strüngmann Forum on Rethinking Global Land Use in an Urban Era	September 23–28, 2012	Frankfurt, Germany	Karen C. Seto and Anette Reenberg,
Telecoupling and Land Change in Emerging Economies: Trade and the Rise of Eco-consumerism (oral session)	March 26, 2012	Planet Under Pressure, London, UK	Eric Lambin, Anette Reenberg, Juliette Caulkins, Tobias Langanke
Telecoupling of Human and Natural Systems (symposium)	February 18, 2011	American Association for the Advancement of Science, Annual Meeting, Washington, DC, USA	Jianguo Liu, William McConnell, Thomas J. Baerwald

3 Overview of the Telecoupling Framework and Applications

The telecoupling framework was first proposed by Liu et al. (2013) and is deeply rooted in coupled human-natural, human-environment or social-ecological systems analysis. Since its inception, it has been applied to develop more specialised frameworks to address specific issues. For example, Eakin et al. (2014) applied the framework to develop an actor-centred approach to telecoupling, and Lenschow et al. (2016) modified the framework from a governance perspective. This chapter provides an overview of the telecoupling framework as developed by Liu et al. (2013) and its applications.

3.1 Overview

The telecoupling framework is an explicit structuring of the telecoupling concept applicable to diverse research questions. The framework uses multiple coupled systems and the connections between them as its main structure (Fig. 2.1). These connections are captured in the framework with the term "flow", which is the movement of materials, people, energy, organisms, capital, and/or information between two or more coupled systems. The coupled system in which the flow originates is termed the "sending system", and the coupled system to which the flow is sent is called the "receiving system". Flows between sending and receiving systems can result in effects on other systems, which are named "spillover systems". The flows among sending, receiving, and spillover systems are a result of "causes", the reasons or drivers behind the flows. There are various causes, such as socioeconomic, environmental, cultural, and other factors. Flows may also induce feedbacks from receiving to sending systems that strengthen, weaken, or alter the flows themselves. The flows are facilitated by "agents", decision-making entities such as people and animals. The flows also generate various socioeconomic and environmental "effects" in the respective systems involved.

An example of a telecoupling is the flow of soybean exports from Brazil, the sending system, to China, the receiving system (Sun et al. 2017;

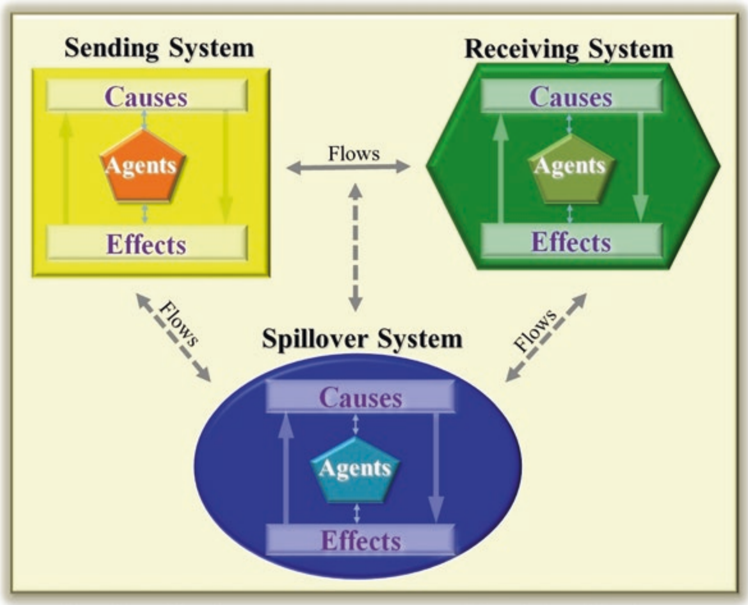

Fig. 2.1 A diagram illustrating the five major and interrelated components of the telecoupling framework (Liu et al. 2013)

Table 2.2). The main agents involved are representatives from Chinese companies that purchase soybeans, Brazilian farmers who plant and sell soybeans, and Chinese consumers driving the demand for soybeans. Causes are the historical use of soybeans as a staple in the Chinese diet, as well as increasing consumption of meat products in China, which require soybean-based feed. Effects of this telecoupling include the conversion of Amazonian rainforest and Cerrado into agricultural lands, with cascading environmental effects (e.g. cropland displacement, greenhouse gas emissions, and loss of carbon storage capacity; Bicudo da Silva et al. 2017; Sun et al. 2017; Liu 2017; Dou et al. 2018). In telecouplings that contribute to climate change, such as this one, the rest of the world can be considered a spillover system. This example is just one in a myriad of applications—the telecoupling framework can be applied to diverse research questions and used with interdisciplinary methodologies to measure and analyse its different components.

Table 2.2 Example systems, flows, agents, causes, and effects in the application of the telecoupling framework to land use

Paper title and authors	Systems	Flows	Agents	Causes	Effects
Telecoupling, urbanisation, and the unintended consequences of water development aid in Ethiopia (Chignell and Laituri 2016)	USA/United Nations (UN) international aid and development sector, Rural communities, Hydropower production systems	Water, Crops, People, Energy, Technology, Capital, Political/ Cultural influence	Foreign aid agencies, Ethiopian ministries, Development banks, Companies, Nongovernmental organisations (NGOs), Faith-based organisations, Farmers/ Pastoralists, Urban poor, Economists, Politicians, Geoscientists	Push and pull of global markets, Demand for water/food security, technological development	Lower infant mortality, Access to improved water, Competition for land/resources, Loss of traditional livelihoods
Spillover effect offsets the conservation effort in the Amazon (Dou et al. 2018)	Brazilian Cerrado, Brazilian Amazon	Soybeans, Beef, Information (policy, agreements, markets), Money	Farmers, Grain buyers, Ranchers, Livestock processing facility, Government, NGOs	China's demand, Brazilian national policy	Deforestation

(*continued*)

Table 2.2 (continued)

Paper title and authors	Systems	Flows	Agents	Causes	Effects
The Emerging Soybean Production Frontier in Southern Africa: Conservation Challenges and the Role of South-South Telecouplings (Gasparri et al. 2016)	South America, Southern African countries	Technology, Investment, Information	Extension agents, Governments, Universities, Development agencies, Companies	Favourable institutional conditions, Demand for soybean products	Increased soy production in South Africa
Telecoupled land-use changes in distant countries (Sun et al. 2017)	Western corn belt (USA), State of Mato Grosso (Brazil), Heilongjiang Province (China)	Soybeans, Money, Information	Governments, NGOs, Companies, Farmers	International food trade	Land-use change
Transatlantic wood pellet trade demonstrates telecoupled benefits (Parish et al. 2018)	Southeastern USA forests, European biopower facilities	Wood pellets, Money, Greenhouse gas emissions	Forest owners, Logging companies, Lumber mills, Coal companies, Miners, Governments, Power companies, Power consumers	EU Renewable Energy Directive	Fire-preventing practices in south-eastern USA, afforestation in Europe

(*continued*)

Table 2.2 (continued)

Paper title and authors	Systems	Flows	Agents	Causes	Effects
Forest sustainability in China and implications for a telecoupled world (Liu 2014)	China, Timber-producing countries (e.g. USA)	Forest products	Companies, Governments, International organisations, NGOs	Limited domestic supply and growing demand in China, Transition from socialism to capitalism	Varying deforestation rates in China and other Asia-Pacific countries
Telecoupling framework for research on migratory species in the Anthropocene (Hulina et al. 2017)	Breeding habitat, Overwintering habitat, Migratory stopover sites	Kirtland's Warblers, Tourism, Timber, Information, Money	Kirtland's Warblers, Brown-headed Cowbirds, Government agencies, NGOs, Timber and tourism companies, Landowners, Farmers	Socioeconomic incentives and social norms to support conservation	Synergism between socioeconomic and environmental efforts

(*continued*)

Table 2.2 (continued)

Paper title and authors	Systems	Flows	Agents	Causes	Effects
Operationalising the telecoupling framework for migratory species using the spatial subsidies approach to examine ecosystem services provided by Mexican free-tailed bats (Lopez-Hoffman et al. 2017)	Texas, New Mexico, and Colorado (USA); Chiapas, Hidalgo, Michoacán & Jalisco, Querétaro (Mexico)	Migratory species, Tourism	Mexican Free-tailed Bats, Tourists, Cotton producers	Bat migration patterns	Spatial subsidy in ecosystem services

3.2 Applications of the Telecoupling Framework

Since publication of the paper outlining the telecoupling framework (Liu et al. 2013), there has been a broad interest in the framework and its applications. Many telecoupling-related events, such as workshops and symposia, have been organised in many parts of the world (Table 2.1). The Global Land Programme has chosen telecoupling as a research priority,[1] and it is being applied in the global assessment of biodiversity and ecosystem services report, organised by the United Nations' Intergovernmental Platform on Biodiversity and Ecosystem Services. A number of projects on telecoupling have been supported by different funding sources, such as the U.S. National Science Foundation,[2] European Union,[3] and Belmont Forum.[4]

The telecoupling framework has been applied in a wide range of studies covering topics from species invasion and migration (Liu et al. 2014; Hulina et al. 2017), urbanisation and economic development (Fang and Ren 2017) to trade, tourism and foreign direct investment (Liu et al. 2015; Yang et al. 2016; Torres et al. 2017). The framework is also gaining traction in studies of land change driven by food trade, knowledge transfers, payment for ecosystem services and conservation (Liu 2014, 2017; Chignell and Laituri 2016; Friis and Nielsen 2017b; Hulina et al. 2017; Lopez-Hoffman et al. 2017; Sun et al. 2017). Given the theme of this book, in this section we illustrate some applications of the framework to land use. Due to space constraints, we focus on example publications that both cite telecoupling in the title and use framework components in relation to land use. The papers included address various agents-individual (e.g. farmers, ranchers, tourists), organisational (e.g. governments, NGOs, companies) and even non-human agents (e.g. migratory birds and bats). The flows include movements of agricultural and timber products, investments, information, technology, people, water, and energy (Table 2.2).

Regardless of the specific topics to which the telecoupling framework is applied, feedbacks between different systems are an important feature of all telecouplings. However, they are often difficult to detect empirically because they take time to form. Spatial separation poses additional challenges for detection. However, Chignell and Laituri (2016) applied the telecoupling framework to urban land expansion driven by clean water initiatives in rural areas of Ethiopia that caused a feedback of rural migrants. They found that the initiatives successfully reduced mortality rates and eventually led to population growth with increased resource competition between young adults. This drove rural migrants to urban areas in search of employment opportunities; the expanding population increased urban resource requirements, which prompted the construction of additional hydropower dams. The constructed dams generated electricity for distant cities, but displaced water resources for downstream communities. This then led to further rural-to-urban migration. The authors acknowledge the usefulness of applying the telecoupling framework in their analysis to "identify potential linkages and feedbacks among distant communities and systems" (Chignell and Laituri 2016, 133).

Spillover systems have been identified at both regional and national scales. At the regional scale, for example, Dou et al. (2018) focused on agents facilitating grain production in Brazil, which generated spillover production areas within the focal country. They modelled the response of farmer-agents to the Soy Moratorium in the Brazilian Amazon and identified the Cerrado as a spillover area of soybean expansion. At the national scale, Liu et al. (2014) used the telecoupling framework to identify spillover systems associated with transnational land deals. For instance, South Africa is a spillover system because it facilitates flows of financial capital to land-title-sending countries from receiving countries.

Going beyond elusive feedbacks and spillovers, the telecoupling framework has been used to bring a more complete understanding of the causes and effects of telecouplings. By enabling evaluation of the socioeconomic and environmental reasons (i.e. causes) for telecoupled flows, the telecoupling framework allows researchers to develop robust explanations of telecouplings. The systematic nature of the telecoupling framework provides a foundation for distinguishing effects (i.e. changes in outcomes brought about by changes in explanatory variables) and mechanisms (i.e. processes whereby explanatory variables produce their effects) (Meyfroidt 2016). In turn, discerning between these causal components can yield unexpected insights that are important for land-use policy and management. For example, Parish et al. (2018) used the telecoupling framework to examine the sale of wood pellets from the USA (i.e. sending system) to European biopower facilities (i.e. receiving system). They concluded that transatlantic wood pellet trade not only reduces European carbon emissions, but also protects European afforestation efforts and encourages management practices that can prevent the spread of wildfires and disease outbreaks throughout the south-eastern USA. Due to negative environmental perceptions of wood pellet trade, understanding the nuances of the telecoupled relationships, including less evident beneficial effects, is essential to maintain jobs and ecosystem services on both sides of the Atlantic Ocean. Further support for untangling complex drivers can be seen in Liu (2014), where China is defined as both a receiving system of forest materials and a sending system of forest products. Liu found that while China is offsetting its domestic wood demand by importing raw materials (e.g. from the USA, Russia, Indonesia, and Canada) and benefiting environmentally, China is also responding to export demand for forest products in other countries (e.g. Japan, South Korea, the USA, and the U.K.). In this light, China is seen not simply as a dominant wood importer, but also as a member of the supply chain, which provides insight for ways to appropriately address forest harvest. For example, policies and initiatives focused on reduced consumption and reuse of finished timber products in the countries importing them from China will likely have greater overall success in reducing forest loss than policies just focused on timber use within China itself.

Use of the telecoupling framework in studies that explicitly analyse the flows between distant places has demonstrated the need for telecoupled land management. For example, Hulina et al. (2017) showed that collaborative management in the sending (breeding) and receiving (wintering) systems for the migration of Kirtland's Warbler (*Setophaga kirtlandii*; a songbird of conservation concern) has resulted in increases in population size and suitable habitats through targeted timber harvest, heterogeneous agriculture landscapes, and tourism. While this is a success story of telecoupled land management, the authors note the lack of collaborative management in spillover systems (migratory stopover sites) that are crucial to sustain the Kirtland's Warbler as well as many other migratory species. Similarly, Lopez-Hoffman et al. (2017) estimate that the cotton producers in south-eastern USA receive pest control benefits (US $12.4

million a year) from flows of the migratory Mexican free-tailed bat (*Tadarida brasiliensis mexicana*), but they provide little support for bat conservation. In other words, the receiving systems of the migratory bats are being spatially subsidised by conservation efforts in the sending systems. Thus, telecoupled land management may be critical to realise the benefits of distant ecosystem services and identify hidden environmental costs.

4 Further Clarifications of the Telecoupling Framework

Since the publication of the telecoupling framework (Liu et al. 2013), there have been some divergent interpretations of its scope and utilisation. While the intentions of those interpretations are good as they aim to bring the field forward, they have unintentionally led to the propagation of further divergence from what the framework was intended to encompass. The different interpretations may be partially due to the lack of explicit statements in the telecoupling framework. Thus, in this section, we clarify these issues to avoid future misunderstanding and misinterpretations.

4.1 Structure of the Telecoupling Framework

The telecoupling framework is both structured and processual. The framework is structured in that it has identifiable components that are used to describe telecouplings. It is also processual as the flows themselves and their feedbacks are processes. Depending on the research questions being asked, an approach that focuses on the structural aspects of a telecoupling (e.g. quantifying system dynamics) will provide a different set of answers than a processual approach (e.g. quantifying the flows between sending and receiving systems). These differing analytical approaches to telecouplings are similar to the way in which ecosystems are defined, understood, and analysed. An ecosystem is defined as an entity encompassing the biotic community and abiotic environment (from a structural perspective), as well as a series of flows between particular components (from a processual perspective); some researchers have studied ecosystem structure, whereas others have studied the process by which interactions within an ecosystem occur (e.g. through nutrient cycling). Extending this example into human systems, an economy consists of producers, consumers, and distributors (structural), as well as relevant processes such as production, consumption, and distribution, that is, the transfers of goods and services between producers and consumers through distributors (processual).

The telecoupling framework can be employed to track changes in system dynamics over time. Telecouplings are usually dynamic and the telecoupling framework can be applied to analyse them retrospectively, contemporarily, and prospectively. Temporal dynamics are inherent to the framework, as telecouplings arise over time to result in current conditions. Likewise, temporal analyses can be used to track the strength of a telecoupling over time and to analyse potential changes to systems in the future. For example, the effects of one telecoupling process could serve as the cause of the emergence of a new telecoupling. Several telecoupling projects aim to understand contemporary land system change and/or project patterns of land change into the future (Millington et al. 2017; Dou et al. 2018). For example, Dou et al. (2018) modeled the response of farmer-agents in the Brazilian Amazon to the Soy Moratorium, which prevented farmers from clearing forest for soybean expansion. This policy displaced soybean expansion to the nearby Cerrado, generating an emergent soybean frontier. Through statistical projections, they estimated the deforestation that would have occurred between 2006 and 2015 in both the sending and spillover systems in the absence of the Soy Moratorium. Agent-based and simulation models are useful tools for understanding and simulating future long-term dynamics (e.g. of land-use change) resulting from telecoupling processes (Millington et al. 2017; Dou et al. 2018).

Receiving and sending systems can be active or passive. In any given telecoupling, it is not predetermined that sending systems are active and receiving systems are passive (e.g. Friis et al. 2016). Rather, the power dynamics or factors that trigger the telecoupling or dominate the telecoupling processes depend on specific circumstances. In other words, a sending system can be passive and a receiving system can be active, or vice versa. Many transnational land deals or land grabs are good examples, with countries buying land (i.e. the receiving systems) pursuing actively while countries from which the land is bought (i.e. the sending systems) acting passively (Liu et al. 2014). In the framework by Liu et al. (2013), causes and agents can occur in sending, receiving, and spillover systems. Together, they make a telecoupling possible. Moreover, many telecouplings work in two directions (e.g. flows of capital and biofuel researchers to Sierra Leone, flows of biofuels and knowledge to Europe; Oberlack et al. 2018), implying that power is distributed and sending and receiving systems can be considered "active" or "passive" depending on the flow considered.

4.2 Implementation of the Telecoupling Framework

The telecoupling framework is both comprehensive and flexible. Because the framework consists of five interrelated major components, it may be perceived as a "check list" (Friis et al. 2016). While checking the box for each telecoupling component does not represent the utility of the framework as a whole (as further analytical approaches are necessary to result in an adequate understanding of a telecoupling), the advantages of a systematic approach include the ability to holistically identify research gaps by comprehensively identifying all aspects of a telecoupling as well as their relationships (see Liu and Yang 2013). For instance, identifying the systems, flows, agents, causes, and effects of a telecoupling, as well as the relationships among them, often reveals complex dynamics (e.g. feedbacks, legacy effects, regime shifts). The framework is also flexible, depending on research goals and questions. For instance, the definition of sending and receiving system is dependent on the flow direction. In other words, the same system may be the sender of one flow, but the receiver of another. Take Liu et al. (2014) as an example—the main flow of interest was the transfer of land titles. Countries that provide land titles to foreign investors were classified as sending systems, whereas those obtaining land titles were classified as receiving systems. Counter-flows of capital (which can also be viewed as feedbacks) went from the receiving to the original sending systems. Nearly all telecouplings will have feedback-flow relationships, which can be accounted for in the framework and associated analyses. If the aim of the above example was to analyse the flow of the monetary investments instead of land titles, the analysis could readily be reversed, demonstrating the efficacy of the telecoupling framework for assessing diverse kinds of telecoupled flows. Rather than restrictive descriptors for unidirectional movements, sending system and receiving system are intuitive conceptual labels for evaluating flows in any direction in which they occur, regardless of research topic. Indeed, this inherent flexibility is an important reason behind the telecoupling framework's wide applicability and utility for addressing global challenges.

Uncovering unexpected or unforeseen effects. Telecouplings may or may not lead to unexpected effects. The types of effects vary greatly. While many effects may be planned or anticipated by researchers (e.g. based on theoretical understanding), some may be surprising or unexpected. For example, it is intuitive that soybean production in Brazil and the USA for exportation consumes domestic water and land. It is a conventional wisdom that exporting countries suffer environmentally while importing countries gain environmental benefits (Sun et al. 2018). However, applying the telecoupling framework changed this conventional wisdom by demonstrating that soybean importing countries also suffer environmental damage, such as higher nitrogen pollution and water consumption, from the soybean trade (Sun et al. 2018). These environmental problems occur because soybean imports cause the conversion of soybean lands to other croplands, such as corn fields and rice paddies, that use more fertilisers and water (Sun et al. 2018). Many of the studies described above also uncovered surprising results, such as more rural-to-urban migration driven by the clean water initiatives (Chignell and Laituri 2016), positive socioeconomic and environmental benefits from transatlantic wood pellet trade (Parish et al. 2018), and increased soybean expansion in the Cerrado in response to the reduction in soybean expansion rates in the Brazilian Amazon (Dou et al. 2018).

The framework is feasible to implement and has numerous analytical entry points. For feasible implementation of the framework, one does not have to work on every component for every project. Like almost any research, if one wants to have extensive, in-depth analysis of a subject, the research would be very time-consuming and resource-intensive. The framework by Liu et al. (2013) provides a comprehensive scope and flexibility. Because a paper is usually limited in space, it is possible to focus on one component for detailed analysis in the context of the framework. For example, five papers can each address one component in detail, and the sixth paper can integrate the previous five. In fact, some applications only focus on receiving systems (Yang et al. 2018) or sending systems (Bicudo da Silva et al. 2017; Dou et al. 2018), while other applications focus on flows (Lopez-Hoffman et al. 2017) or agents, causes, and effects (Friis and Nielsen 2017a). Working on different components under the framework separately maintains feasibility while providing a mechanism for collaborative, team-based research and an avenue for integration in the future. Although it is generally infeasible to "know everything" about a topic, particularly complex coupled human-natural systems, forming cooperative research teams is a practical way to implement the telecoupling framework and maximise its utility for addressing sustainability challenges. Further, due to its flexible nature, any component of the telecoupling framework can be an analytical entry point. A telecoupling analysis can therefore start by identifying flows between, agents involved in, and causes and/or effects of connected systems. For example, Leisz et al. (2016) used qualitative methods along with remote-sensing analysis to quantify land-use change along the East-West Economic Corridor in Southeast Asia from both a system-based and agent-based entry point.

System boundaries are context-dependent and need not be defined a priori. Defining system boundaries is important because different boundaries may lead to different outcomes. However, the framework does not finalise the definition of a system *a priori* and is flexible regarding the method for determining system boundaries. Depending on problems and questions of interest, systems may be defined by spatial units; cultural networks; or geographical, political, administrative, or management boundaries (see also Eakin et al. 2014; Friis and Nielsen 2017a). The time at which the system definition is finalised is also important. Friis and Nielsen (2017a) have expressed concern that defining systems *a priori* risks hiding the complexity of telecoupling. Many telecoupling studies take multiple steps and do not finalise system boundaries until after the first steps (Liu 2017). To save space, however, the detailed processes during the early steps leading to the system definition are often omitted from publications (Liu et al. 2015). The lack of reporting the early steps may cause the reader to perceive that the system is defined *a priori*. In fact, the systems under the telecoupling framework do not need to be and often cannot be finalised *a priori*. For example, the sending systems of tourists to Wolong Nature Reserve of China were not known until the interviews with tourists were completed and the interview data were analysed (Liu et al. 2015). More explicit descriptions of the definition of system boundaries, the reasons for defining these boundaries, and the potential effects of these boundary definitions should be undergone in future studies in order to improve transparency and research practice.

Application of the telecoupling framework at multiple scales is possible and may reveal unexpected scale dependencies. The dependency of a conclusion on the scale of analysis is a common issue in a variety of sciences and can affect applications of the telecoupling framework. The advantage of the framework is that its components can change according to the scale chosen for analysis. Friis and Nielsen (2014) present an example of rubber plantation development in Laos (receiving system) that is driven by Chinese investment from the Xishuangbanna region (sending system). By increasing the spatial and temporal scale, they reframed the problem so that rubber production in Xishuangbanna (receiving system) was driven by investments from Beijing (sending system), and Laos became a spillover system for excess rubber demand unable to be met by Xishuangbanna alone.

4.3 Implications for Telecoupled Governance

Facilitating the shift from place-based governance to flow-based governance. Recently, attention has been paid to the increasing shift in land governance from traditional place-based governance (i.e. focusing on governance or management of individual places) to flow-based governance arrangements, which emphasise that governance of one system should consider its relationships with other systems, including flows between them (Sikor et al. 2013). For example, Hulina et al. (2017) propose to expand the Kirtland's Warbler management paradigm from sitebased to flow-based across sending systems (breeding sites), receiving systems (wintering sites), and spillover systems (e.g. stopover sites of the warbler migration, hometowns of tourists who travel to see the warbler). Because the warbler populations in wintering and breeding sites have reciprocal effects, land use in all sites affects the total population. Flows of money and tourists from other places to wintering and breeding sites are important for generating conservation funds. Eliminating or minimising the flow of Brown-headed Cowbirds (*Molothrus ater*) to breeding sites can reduce warbler mortality. This case is a clear example of the need for cooperation among agents in sending, receiving, and spillover systems to achieve flow-based governance. Flow-based governance of telecoupled interactions has also recently been suggested in food systems (Eakin et al. 2017) and biofuel production (Oberlack et al. 2018). Eakin and colleagues argue that social, institutional, and physical distances between systems can drive the capacity for changes in governance, and Oberlack and colleagues suggest a more integrated approach in linking polycentric governance with the telecoupling framework through the analysis of action/outcome networks. Such innovative analyses and approaches are needed for applied governance in a world increasingly connected via complex pathways.

Addressing global challenges. The telecoupling framework has important implications for addressing global challenges such as biodiversity conservation, food security, water security, and human well-being (Liu 2017). As an example, biofuel policies exert socioeconomic and environmental effects (e.g. land-use change; physical and economic displacement; decreased access to natural, economic, and cultural resources) in distant areas of the world (Oberlack et al. 2018). Because these impacts complicate efforts to address food and water security, there is a pressing need for governance that recognises telecouplings (i.e. telecoupled governance) associated with global biofuel production. The telecoupling framework can help address these and other global challenges (e.g. Sustainable Development Goals, biodiversity conservation) because it provides a systematic method for identifying the systems, flows, agents, causes, and effects associated with land-use changes. By operationalising the assessment of distant human-nature interactions, the telecoupling framework can help reveal the complexity of land use, aid managers in characterising global interconnectedness related to land use, and generate novel insights about land-use dynamics. Ultimately, this knowledge can catalyse the development of adaptive land-use policy and management strategies that promote telecoupled, polycentric governance (Oberlack et al. 2018) to solve global challenges.

4.4 Current Limitations of the Telecoupling Framework

As with all new frameworks, operationalising the telecoupling framework in all contexts will take time and effort. For a variety of reasons, such as researchers' interests and data limitations, some applications of the framework only focus on one or two of its particular aspects. Research gaps are thus inherent to this process of separately analysing individual telecoupling components. Specific areas that have been understudied include how telecouplings emerge and dissolve, their impact on sustainability and best practices for encouraging positive rather than negative impacts, and more explicit accounting for local and regional interactions in a broader context (see metacoupling framework below; Liu 2017). Further operationalisation of the telecoupling framework for quantitative and qualitative analyses of environmental and socioeconomic issues will help to address current limitations and future challenges.

5 Perspectives and Conclusions

In a world that is increasingly interconnected, the telecoupling framework offers a foundational tool to analyse linkages between systems over multiple scales, across distance, and through time. This chapter provided an overview of the telecoupling framework and highlighted several of its applications, drawing attention to the complex nature of telecoupling processes and the importance of feedback and spillover effects. The ability of the telecoupling framework to reveal connected, yet temporally or spatially separate effects underscores the importance of telecoupled, flow-based governance to harmonise human well-being with environmental sustainability.

Looking forward, there are many opportunities for telecoupling research in the future. In particular, the novelty of the telecoupling framework creates many opportunities for operationalising the framework to integrate previously isolated disciplinary research into a more holistic understanding of the socioeconomic and ecological aspects of distant interactions. Operationalisation of the telecoupling framework using geospatial analytical tools like those developed by Tonini and Liu (2017) as part of a new "Telecoupling Toolbox" can aid in the creation of telecoupled governance systems and help to address global challenges, such as those identified by the Sustainable Development Goals. Likewise, applying the telecoupling framework to identify previously unknown spillover systems and feedbacks is a critical component of future telecoupling research. As demonstrated in this chapter, policies intended to curb undesirable impacts in one system may displace these impacts to other systems not subject to the policy. Similarly, without the use of the framework, feedbacks from telecoupled flows are poorly understood due to temporal and spatial lags and may result in unintended consequences. Applications of the telecoupling framework to different systems can help detect hidden linkages and improve the management of telecoupled systems. Also, telecoupled systems are part of metacoupled systems, which encompass intracoupling (human-nature interactions within a system) and pericoupling (human-nature interactions between adjacent systems), in addition to telecoupling (Liu 2017). Understanding interactions among different types of couplings such as the interrelationships between telecouplings and pericouplings/intracouplings can help more holistically unveil the complexity of the real world to better address the Sustainable Development Goals and other global challenges.

Acknowledgments We thank Jonas Ø. Nielsen and Cecilie Friis for their invitation to write this chapter, and Cecilie Friis, Jonas Ø. Nielsen and Christoph Oberlack for reviewing the early draft. Funding was provided by the U.S. National Science Foundation and Michigan AgBioResearch.

Notes

1. https://glp.earth/our-science/themes/telecoupling-land-use-systems
2. https://www.nsf.gov/awardsearch/showAward?AWD_ID=1518518
3. http://coupled-itn.eu
4. http://www.belmontforum.org/projects/food-security-and-land-use-the-telecoupling-challenge/

References

Bicudo da Silva, Ramon F., Mateus Batistella, Yue Dou, Emilio F. Moran, Sara M. Torres, and Jianguo Liu. 2017. The Sino-Brazilian Telecoupled Soybean System and Cascading Effects for the Exporting Country. *Land* 6 (53): 1–19.

Chignell, Stephen M., and Melinda J. Laituri. 2016. Telecoupling, Urbanisation, and the Unintended Consequences of Water Development Aid in Ethiopia. In *Geoscience for the Public Good and Global Development: Toward a Sustainable Future*, ed. Gregory R. Wessel and Jeffrey K. Greenberg. Boulder, CO: Geological Society of America.

Dou, Yue, Ramon F. Bicudo da Silva, H. Yang, and Jianguo Liu. 2018. Spillover Effect Offsets the Conservation Effort in the Amazon. *Journal of Geographical Sciences* 28 (11): 1715–1732.

Eakin, Hallie, Ruth DeFries, Suzi Kerr, Eric F. Lambin, Jianguo Liu, Peter J. Marcotullio, Peter Messerli, Anette Reenberg, Ximena Rueda, Simon R. Swaffled, Birka Wicke, and Karl Zimmerer. 2014. Significance of Telecoupling for Exploration of Land-Use Change. In *Rethinking Global Land Use in an Urban Era*, ed. Karen Seto and Anette Reenberg, 141–161. Cambridge, MA: The MIT Press.

Eakin, Hallie, Ximena Rueda, and Ashwina Mahanti. 2017. Transforming Governance in Telecoupled Food Systems. *Ecology and Society* 22 (4): 32. https://doi.org/10.5751/ES-09831-220432.

Fang, Chuang Lin, and Yu Fei Ren. 2017. Analysis of Energy-based Metabolic Efficiency and Environmental Pressure on the Local Coupling and Telecoupling between Urbanisation and the Eco-environment in the Beijing-Tianjin-Hebei Urban Agglomeration. *Science China Earth Sciences* 60 (6): 1083. https://doi.org/10.1007/s11430-016-9038-6.

Friis, Cecilie, and Jonas Ø. Nielsen. 2014. Exploring the Potential of the Telecoupling Framework for Understanding Land Change. *THESys Discussion Papers 1*. Berlin: IRI THESys, Humboldt-Universität zu Berlin.

———. 2017a. On the System Boundary Choices, Implications and Solutions in Telecoupling Land-Use Change Research. *Sustainability* 9: 974.

———. 2017b. Land-Use Change in a Telecoupled World: The Relevance and Applicability of the Telecoupling Framework in the Case of Banana Plantation Expansion in Laos. *Ecology and Society* 22 (4): 30. https://doi.org/10.5751/ES-09480-220430.

Friis, C., J.Ø. Nielsen, I. Otero, H. Haberl, J. Niewöhner, and P. Hostert. 2016. From Teleconnection to Telecoupling: Taking Stock of an Emerging Framework in Land System Science. *Journal of Land Use Science* 11 (2): 131–153. http://www.tandfonline.com/doi/full/10.1080/1747423X.2015.1096423.

Gasparri, N.I., T. Kuemmerle, P. Meyfroidt, Y. le Polain de Waroux, and H. Kreft. 2016. The Emerging Soybean Production Frontier in Southern Africa: Conservation Challenges and the Role of South-South Telecouplings. *Conservation Letters* 9 (1): 21–31. https://doi.org/10.1111/conl.12173.

Haberl, Helmut, Karl-Heinz Erb, Fridolin Krausmann, Stefan Berecz, Nikolaus Ludwiczek, Joan Martínez-Alier, Annabella Musel, and Anke Schaffartzik. 2009. Using Embodied HANPP to Analyze Teleconnections in the Global Land System: Conceptual Considerations. *Geografisk Tidsskrift-Danish Journal of Geography* 109 (2): 119–130. https://doi.org/10.1080/00167223.2009.10649602.

Hulina, Jacqueline, Carol Bocetti, Henry Iii, Vanessa Hull, Wu Yang, and Jianguo Liu. 2017. Telecoupling Framework for Research on Migratory Species in the Anthropocene. *Elementa—Science of the Anthropocene* 5: 5. https://doi.org/10.1525/elementa.184.

Leisz, J. Stephen, Eric Rounds, Ngo The An, Nguyen Thi Bich Yen, Tran Nguyen Bang, Souvanthone Douangphachanh, and Bounheuang Ninchaleune. 2016. Telecouplings in the East-West Economic Corridor within Borders and Across. *Remote Sensing* 8 (12): 1012. https://doi.org/10.3390/rs8121012.

Lenschow, Andrea, Jens Newig, and Edward Challies. 2016. Globalisation's Limits to the Environmental State? Integrating Telecoupling into Global Environmental Governance. *Environmental Politics* 25 (1): 136–159. https://doi.org/10.1080/09644016.2015.1074384.

Liu, Jianguo. 2014. Forest Sustainability in China and Implications for a Telecoupled World. *Asia and the Pacific Policy Studies* 1: 230–250. https://doi.org/10.1002/app5.17.

———. 2017. Integration Across a Metacoupled World. *Ecology and Society* 22 (4): 29. https://doi.org/10.5751/ES-09830-220429.

Liu, Jianguo, Vanessa Hull, Mateus Batistella, Ruth DeFries, Tom Dietz, Fu Feng, Thomas W. Hertel, R. Cesar Izaurralde, Eric F. Lambin, Shuxin Li, Luiz A. Martinelli, William J. McConnell, Emilio F. Moran, Rosamond Naylor, Zhiyun Ouyang, Karen R. Polenske, Anette Reenberg, Gilberto de Miranda Rocha, Cynthia S. Simmons, Peter H. Verburg, Peter M. Vitousek, Fusuo Zhang, and Chunquan Zhu. 2013. Framing Sustainability in a Telecoupled World. *Ecology and Society* 18 (2): 26. https://doi.org/10.5751/ES-05873-180226.

Liu, Jianguo, Vanessa Hull, Junyan Luo, Yang Wu, Wei Liu, Andrés Viña, Christine Vogt, Zhenci Xu, Hongbo Yang, Jindong Zhang, Li An, Xiaodong Chen, Shuxin Li, Zhiyun Ouyang, Weihua Xu, Hemin Zhang, and Hemin Zhang. 2015. Multiple Telecouplings and their Complex Interrelationships. *Ecology and Society* 20 (3): 44. https://doi.org/10.5751/ES-07868-200344.

Liu, Jianguo, Vanessa Hull, Emilio Moran, Harini Nagendra, Simon R. Swaffled, and Benjamin L. Turner II. 2014. Applications of the Telecoupling Framework to Land-Change Science. In *Rethinking Global Land Use in an Urban Era*, ed. Karen C. Seto and Anette Reenberg, 119–139. Cambridge, MA: The MIT Press.

Liu, Jianguo, and Wu Yang. 2013. Integrated Assessments of Payments for Ecosystem Services Programs. *Proceedings of the National Academy of Sciences* 110 (41): 16297–16298. https://doi.org/10.1073/pnas.1316036110.

Lopez-Hoffman, Laura, Jay Diffendorfer, Ruscena Wiederholt, Kenneth J. Bagstad, Wayne E. Thogmartin, Gary McCracken, Rodrigo L. Medellin, Amy Russell, and Darius J. Semmens. 2017. Operationalizing the Telecoupling Framework for Migratory Species Using the Spatial Subsidies Approach to Examine Ecosystem Services Provided by Mexican Free-Tailed Bats. *Ecology and Society* 22 (4): 23. https://doi.org/10.5751/ES-09589-220423.

Meyfroidt, Patrick. 2016. Approaches and Terminology for Causal Analysis in Land Systems Science. *Journal of Land Use Science* 11 (5): 501–522.

Millington, James David Anthony, Hang Xiong, S. Peterson, and J. Woods. 2017. Integrating Modelling Approaches for Understanding Telecoupling: Global Food Trade and Local Land Use. *Land* 6 (3): 56. https://doi.org/10.3390/land6030056.

Oberlack, Christoph, Sebastien Boillat, Stefan Brönnimann, Jean-David Gerber, Andreas Heinimann, Chinwe Ifejika Speranza, Peter Messerli, Stephan Rist, and Urs Wiesmann. 2018. Polycentric Governance in Telecoupled Resource Systems. *Ecology and Society* 23 (1): 16. https://doi.org/10.5751/ES-09902-230116.

Parish, Esther S., Herzberger Anna, C. Phifer, and Virginia H. Dale. 2018. Telecoupled Transatlantic Wood Pellet Trade Provides Benefits in Both the Sending and Receiving Systems. *Ecology and Society* 23 (1): 28. https://doi.org/10.5751/ES-09878-230128.

Sassen, S. 1999. *Globalisation and Its Discontents: Essays on the New Mobility of People and Money*. New York: The New Press.

Seto, Karen C., and Anette Reenberg, eds. 2014. *Rethinking Global Land Use in an Urban Era*. Cambridge, MA: The MIT Press.

Seto, Karen C., Anette Reenberg, Christopher G. Boone, Michail Fragkias, Dagmar Haase, Tobias Langanke, Peter Marcotullio, Darla K. Munroe, Branislav Olah, and David Simon. 2012. Urban Land Teleconnections and Sustainability. *Proceedings of the National Academy of Sciences* 109 (20): 7687–7692. https://doi.org/10.1073/pnas.1117622109.

Sikor, Thomas, Graeme Auld, Anthony J. Bebbington, Tor A. Benjaminsen, Bradford S. Gentry, Carol Hunsberger, Anne-Marie Izac, Matias E. Margulis, Tobias Plieninger, Heike Schroeder, and Caroline Upton. 2013. Global Land Governance: From Territory to Flow? *Current Opinion in Environmental Sustainability* 5 (5): 522–527. https://doi.org/10.1016/j.cosust.2013.06.006.

Sun, Jing, Harold Mooney, Wenbin Wu, Huajun Tang, Yuxin Tong, Zhenci Xu, Baorong Huang, Yeqing Cheng, Xinjun Yang, Dan Wei, Fusuo Zhang, and Jianguo Liu. 2018. Importing Food Damages Domestic Environment: Evidence from Global Soybean Trade. *Proceedings of the National Academy of Sciences* 115 (21): 5415–5419.

Sun, Jing, Yuxin Tong, and Jianguo Liu. 2017. Telecoupled Land-Use Changes in Distant Countries. *Journal of Integrative Agriculture* 16 (2): 368–376. https://doi.org/10.1016/S2095-3119(16)61528-9.

Tonini, Francesco, and Jianguo Liu. 2017. Telecoupling Toolbox: Spatially Explicit Tools for Studying Telecoupled Human and Natural Systems. *Ecology and Society* 22 (4): 11. https://doi.org/10.5751/ES-09696-220411.

Torres, Aurora, Jodi Brandt, Kristen Lear, and Jianguo Liu. 2017. A Looming Tragedy of the Sand Commons. *Science* 357 (6355): 970.

Wallace, John M., and David S. Gutzler. 1981. Teleconnections in the Geopotential Height Field during the Northern Hemisphere Winter. *American Meteorological Society* 109: 784–812.

Yang, Dewei, Jingjing Cai, Vanessa Hull, Kaiyong Wang, Yin-Phan Tsang, and Jianguo Liu. 2016. New Road for Telecoupling Global Prosperity and Ecological Sustainability. *Ecosystem Health and Sustainability* 2 (10): e01242.

Yang, Hongbo, Frank Lupi, Jindong Zhang, Xiaodong Chen, and Jianguo Liu. 2018. Feedback of Telecoupling: The Case of a Payment for Ecosystem Services Program. *Ecology and Society* 23 (2): 45. https://doi.org/10.5751/ES-10140-230245.

Young, Oran R., Frans Berkhout, Gilberto C. Gallopin, Marco A. Janssen, Elinor Ostrom, and Sander van der Leeuw. 2006. The Globalisation of Socio-ecological Systems: An agenda for Scientific Research. *Global Environmental Change* 16 (3): 304–316. https://doi.org/10.1016/j.gloenvcha.2006.03.004.