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Applications of the Telecoupling Framework to Land-Change Science

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Abstract

Over the past two decades, progress has been made in understanding and predicting land-use change in specific places, using frameworks such as coupled human-natural systems, coupled human-environmental systems, or coupled social-ecological systems. However, land-use change around the world is increasingly being driven by new agents and causes which emanate from distant locations, through forces such as trade, migration, transnational land deals, and species invasions. New conceptual frameworks are thus needed to account for such distant forces. This chapter applies a framework that explicitly takes distant forces into account in land-use change and builds on the concept of telecoupling (i.e., environmental and socioeconomic interactions among coupled systems over large distances). Telecoupling is a logical extension of coupled systems thinking; it draws insights from related concepts in different disciplines and serves as an umbrella concept to address and integrate various types of distant connections between coupled systems. The telecoupling framework includes five major and interrelated components: coupled human-natural systems, agents, flows, causes, and effects. An overview of the telecoupling framework is presented and two examples (transnational land deals and species invasions) demonstrate the application of the framework to global land use. Finally, challenges and opportunities in understanding telecouplings and their consequences are highlighted and calls made for new directions in land-change research.

Introduction

Over the past two decades, many advances have been made in understanding and predicting land-use dynamics at a global scale (Turner et al. 2007). In particular, land-use change has been extensively studied using systems

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frameworks, such as coupled human-natural systems (McConnell et al. 2011; Liu et al. 2007a), coupled social-ecological systems (Walker et al. 2004), or coupled human-environmental systems (Moran 2010; Turner et al. 2003). Coupled systems are integrated systems in which humans and natural components interact. These frameworks view land use as a function of interactions between socioeconomic and ecological factors within a coupled system (i.e., local or internal couplings). Although the frameworks for these systems are helpful in guiding the analysis of internal forces in driving land-use change, they fall short in their consideration of the increasing scale, extent, and speed of existing and emerging connections between coupled systems over large distances.

Distant connections between land-use systems are not new. They can be traced as far back as the third millennium BCE between areas now known as Iraq and India (Frank 1998). They were also present, for example, during the ancient Greek and Roman eras, along various trade routes in Asia, along the Silk Road between ancient China to Europe, and through the Columbian Exchange (following Christopher Columbus's voyage to the Americas in 1492, which led to widespread exchange of animals, plants, humans, food, culture, and ideas between the Western and Eastern Hemispheres) (Nunn and Qian 2010). Great Britain's rise to supremacy as an industrial power in the eighteenth century was also dependent on distant access to raw materials and markets. Modern connections progressed in the nineteenth century with advances in transportation, telecommunication, and economic industrialization (Headrick 1991). Today, even stronger connections have developed between coupled systems around the globe (Lambin and Meyfroidt 2011; DeFries et al. 2010; Seto et al. 2012b; Eakin et al. 2009; Haberl et al. 2009; Nepstad et al. 2006). These connections are related to many of the greatest and most complex challenges that face societies, such as food security, demands for energy, destruction of ecosystems, and biodiversity loss.

To address these unprecedented challenges, new conceptual frameworks are needed to guide analyses of these increasingly important distant interconnections, so that future land use can more accurately be projected and better governance and policies on land-use change can be developed. In this chapter, we present a multidisciplinary conceptual framework for such interconnections and present examples to illustrate key components of the telecoupling framework and their relations to global land use. We highlight challenges and opportunities in addressing telecoupling, and call for new directions in land-change research.

Overview of the Telecoupling Framework

Many disciplines consider interactions between distant systems. The idea that distant places and processes are connected is well established, as is the idea of

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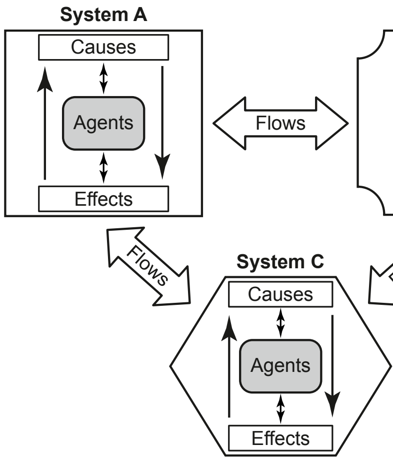

Figure 7.1 Model of the five main interrelated components of the telecoupling framework. *Causes* produce a telecoupling between at least two coupled human and natural *systems*, which generate *effects* that are manifested in one or more coupled human and natural systems. Telecoupling is conducted by *agents* that facilitate or hinder *flows* of material/energy/information between *systems*. Three systems are depicted, each of which can simultaneously serve as sending, receiving, or spillover systems, depending on the flow being analyzed. For further discussion, see Liu et al. (2013).

humans and the environment being connected (Linnaeus 1749/1964; Marsh 1864/1965). For more than a decade, the U.S. National Science Foundation has funded research to study coupled human-natural systems.[1] In atmospheric science, the concept of teleconnections relates to the environmental interactions between climatic systems over considerable distances (Glantz et al. 1991). This teleconnection framework has been applied to social science and land systems (Haberl et al. 2009; Seto et al. 2012b).

The concept of telecoupling used in this chapter builds on concepts such as land teleconnections (Haberl et al. 2009; Seto et al. 2012b), integrated human and environmental systems (Peterson 2000), and globalization (Levitt 1983). A significant feature of telecoupling between distant systems is the role of feedbacks; that is, reciprocal interactions among different coupled systems. The telecoupling framework presented here consists of five main interrelated components (Figure 7.1): systems, agents, flows, causes, and effects (see also Liu et al. 2013). *Causes* generate a telecoupling between a minimum of two coupled human and natural *systems*, which produce *effects* that are evident in one or more of the *systems*. A telecoupling is produced by *agents* that facilitate or hinder the *flows* of material/energy or information among the *systems*. Telecoupling studies differ from multisystem comparison studies in that they

[1] See http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=13681

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explicitly address socioeconomic and environmental interactions between the systems. Figure 7.1 illustrates the key components of telecoupled systems and the terminology used in this chapter; the process relationships between the systems have been further refined by Eakin et al. (this volume).

Systems refer to coupled human-natural systems and are defined as a set of human and natural components interacting to form a whole. Systems can be characterized as sending systems (origins), receiving systems (destinations), or spillover systems. Sending systems send *flows* out, while receiving systems obtain *flows* from the sending systems. *Flows* exchange material, energy, or information between the *systems*. Material or energy includes biophysical and socioeconomic entities (e.g., goods, food, natural resources, organisms, carbon) whereas information includes knowledge and agreements (e.g., trade agreements, land titles, agricultural techniques). Telecoupling *agents* include autonomous decision-making entities within sending, receiving, and/or spillover systems that are directly or indirectly involved in telecouplings, such as via the formation or dissolution of *flows*. They can be individuals or groups of humans or animals (e.g., herds of animals, households, government agencies). Spillover systems form as a byproduct of linkages between sending and receiving systems. Spillover systems may be linked to sending and receiving systems via three main mechanisms (Liu et al. 2013): (a) by serving as an intermediate stopover between two systems (e.g., a migratory bird stopover or airport layover), (b) by being located along the pathway between the sending and receiving systems (e.g., oil spilled during transport), or (c) by engaging with the sending and receiving systems (e.g., a third party in trade negotiations).

The *causes* of telecoupling are factors that generate dynamics (e.g., emergence, changes in strength) of a telecoupling. Most telecouplings have multiple causes which originate from a sending, receiving, and/or spillover system. Five broad categories of causes could include economic, political, technological, cultural, and ecological, although these categories interact with one another. *Effects* refer to environmental and socioeconomic consequences or impacts of a telecoupling. They can be manifested in sending, receiving, and/or spillover systems according to two main interrelated categories: socioeconomic and environmental. Types of effects observed in individual coupled systems (Liu et al. 2007b) may also be manifested in telecoupled systems, including indirect effects, feedbacks, cascading effects, and legacy effects. Effects are often nonlinear and may have time lags (i.e., they do not emerge for years or even decades after the telecoupling is initiated).

Telecoupled systems have a hierarchical structure. At the highest level, flows are transferred between multiple coupled human-natural systems. At the intermediate level, each coupled human-natural system contains agents that facilitate the telecoupling. Causes and effects are primarily manifested at this level. At the smallest subsystem level, each component has particular characteristics of interest to the telecoupling (e.g., individual agents operate within

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multiple, different types of institutions). In addition, cross-level interactions occur, such as when within-system agents facilitate cross-system flows.

Applications of the Telecoupling Framework

To illustrate the application of the telecoupling framework (systems, agents, flows, causes, and effects) to global land use, two very different examples will be used: transnational land deals and species invasions. We chose these two examples, and will provide a general description and specific case for each, because both are gaining importance as drivers for global land-use change through mediating interactions between multiple coupled systems. Additional telecouplings are listed in Table 7.1.

Transnational Land Deals

Throughout history, many communities and nations have exchanged land titles (i.e., rights to use and control land in different ways). Some notable historical exchanges include those between the classical Roman Empire and societies throughout Europe and Asia, the Louisiana Purchase by the U.S. Government from France, as well as numerous smaller land purchases by new immigrants and settlers from indigenous communities. Such "exchanges" of rights were frequently part of wider changes in relations between peoples, such as colonization, or postcolonial governance.

Over the past decade, there have been dramatic increases in different types of transnational large-scale land deals (exchanges of land titles, sometimes described as "land grabs" or a "global land rush") with an unprecedented number of countries involved (see also Hunsberger et al., Margulis, Gentry et al., all this volume). Between 2000 and 2010 a total of 2,042 deals with approximately 203 million hectares of land were reported to have been transferred (Anseeuw et al. 2012b). More than half of these deals (1,155), affecting approximately 71 million hectares, have been cross-referenced (i.e., confirmed via triangulation from different sources) (Anseeuw et al. 2012b). Most of these deals are long-term leases of government-owned land, although some are outright land purchases (Cotula 2012). These land deals increased abruptly in 2007/2008 and peaked in 2009. In 2010 (the most recent year of available data), the number dropped substantially; however, they were still well above the pre-2005 levels (Scherer 2012). The purposes of the recent land deals are more diverse than in the past, which focused mainly on agricultural food and fiber plantations, (Cotula 2012), with notable exceptions such as cacao, which served as currency in the time of the Aztecs in Guatemala. For example, biofuels are now a major factor in many deals. Of the land involved in cross-referenced deals for which the purposes are known, 58% is for biofuel, 17% for food crops, 13%

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Table 7.1 Examples of telecouplings and hypothetical relationships to land use in sending, receiving, and spillover systems. Feedbacks may be common in telecouplings among different systems, although many of them may take a long time to emerge.

Telecouplings	Land Use in Sending, Receiving, and Spillover Systems
Trade of goods and products (e.g., food, energy, timber, medicine, and minerals)	Land is used for producing goods and products in the sending systems. In receiving systems, land may be used for other purposes (e.g., urban, residential) because of a reduced demand for goods and services fulfilled by the sending systems. In spillover systems, land use may be affected in various ways depending on the relationships with sending and spillover systems. In all systems, land may also be used for building facilities to store, transport and distribute goods and products.
Technology transfer (e.g. machinery, pesticides, tillage techniques)	Technology generation occupies land in sending systems (e.g., space for factories). Technology implementation may change land-use efficiency and intensity, and may promote land development (e.g., via powerful machinery) in receiving and spillover systems.
Tourism	Land may be devoted to tourism facilities (e.g., roads, scenic spots, restaurants, hotels) in receiving and spillover systems. Land use in the sending systems may also be changed (e.g., building something similar to what tourists have seen in other systems).
Development investment	Development investment (e.g., transnational land deals) may stimulate land use and land conversion (e.g., for agricultural production, manufacturing facilities) in the receiving systems, may or may not slow down or prevent land development and land conversion in the sending systems, and may influence land use in spillover systems in various ways.
Human migration	Human migrants may (or may not) abandon land in the sending systems and occupy land in the receiving systems (e.g., for housing and work/recreation space). Land use in the spillover systems may vary depending on their relationships with sending and receiving systems.
Knowledge transfer	Knowledge transfer (e.g., theories, techniques, innovations, governance and management approaches) may affect land-use efficiency and land expansion in the receiving and spillover systems. It is not clear whether land use in the sending systems is changed.

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Table7.1 *continued*

Telecouplings	Land Use in Sending, Receiving, and Spillover Systems
Water transfer	Facilities for water transfer (e.g., channels and reservoirs) may take up land in sending, receiving, and spillover systems, and may change land use in all systems.
Waste transfer	Transfer of waste (e.g., electronic waste) may conserve land in the sending systems, but occupy and contaminate land (e.g., landfills, pesticides in croplands) in receiving and spillover systems.
Conservation investment	Conservation investment (e.g., payments for ecosystem services) may conserve and restore land in the receiving systems, may or may not slow down or prevent land development and conversion in the sending systems, and may influence land use in spillover systems in various ways.
Seasonal animal migration	Seasonal animal migrants (e.g., migratory birds) may use land in sending, receiving and spillover systems (e.g., stopover systems) during specific times of the year.
Species invasions	Invasive species occupy and damage land (e.g., crops and native vegetation) in receiving and spillover systems. Land use in the sending systems can be changed through invasion control methods and policies.
Species dispersal	Species dispersal may or may not result in an animal, plant, or microbe occupying less land in the sending systems, but occupying more land in the receiving and spillover systems (e.g., dispersal corridors). Species may improve or harm land quality in each system depending on their specific relationships to land.
Air circulation	Circulation of air may change land composition and land cover (by transporting soil, organisms, and pollutants such as acid rain from one place to another) in the sending, receiving, and spillover systems.

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for forestry, and the remaining 12% for other items (industry, livestock, mineral extraction, and tourism).

Telecoupling Components

Systems A total of 84 sending countries have provided land titles for land deals (Anseeuw et al. 2012a). Among the cross-referenced deals, Africa offered the largest share of land titles, with ca. 34 million hectares between 2000 and 2010. Asia supplied the second largest share (~29 million hectares), followed by Latin America (~6 million) (Anseeuw et al. 2012a). Other regions such as Eastern Europe and Oceania also offered land, but these offers were much smaller (1.6 million hectares).

There are a total of 76 land-title-receiving countries (or investor countries) (Anseeuw et al. 2012a). Of the cross-referenced deals, two-thirds (66.9%) of the land titles went to Asia. Europe, Africa, North America, and Latin America received 11.6%, 10.2%, 8.5%, and 2.7% respectively. The United States, Malaysia, United Kingdom, China, United Arab Emirates, South Korea, India, Australia, South Africa, and Canada are the top ten receiving countries.[2] A number of countries both offered and received land titles. These include Brazil, China, India, and South Africa. Although Brazil offered 27 times more than it received, the other three countries showed the opposite trend, that is, China, India, and South Africa received 9, 14, and 132 times more than they offered, respectively.

Some countries are important spillover systems, which facilitate investment from receiving countries to land-title-sending countries. For example, South Africa has played such a role due to its geographic proximity to land-title-receiving countries and expertise in agriculture throughout Africa (Cotula 2012). Mauritius is another spillover country because of its tax regime and its bilateral investment treaties with other countries in Africa, such as Mozambique (Cotula 2012).

Agents. Numerous agents have been engaged directly and indirectly in land deals. Private companies have been directly responsible for most of the land deals. They have also received diplomatic, financial, and policy support from their governments. Some of the agents are state-owned companies (e.g., China National Cereals, Oils and Foodstuffs Import and Export Company). In fact, for some land-receiving countries, land deals were initiated by their governments. The governments of land-sending countries are also deeply involved in land deals, from providing information to investors, to attracting investors through handsome incentives, to deal approval and implementation. National elites are also often key agents (Anseeuw et al. 2012a). Many international

2 Data from http://landportal.info/landmatrix

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organizations play facilitating roles. For example, the World Bank has promoted a good investment environment in some African countries to provide easier access to land by foreign investors (Daniel and Mittal 2010).

Flows. The primary flows involved in land deals include land titles (i.e., rights) transferred from the sending countries to receiving countries, and money to purchase the land titles transferred from the receiving countries to the sending countries. There are also consequential flows of people, machines, and techniques (e.g., crop varieties, pesticides, and fertilizers) transferred by the land title receiving countries to the sending countries to develop the land. Products produced on the land are then sent to receiving and spillover countries all over the world. These include timber, biofuel, food, nonfood crops such as rubber, and other raw materials such as minerals and gas (Anseeuw et al. 2012a). Hence the initial telecoupling (in this case purchase and transfer of land titles) acts as a catalyst for more complex flow patterns.

Causes. The key economic cause of transnational land deals is the interplay between global land supply and demand. The world is heterogeneous in terms of supply and demand. Large and fast-growing economies with relatively scarce land, such as China and India, create ever-increasing demands for land because of their economic growth and increased consumption of animal-based products and other land-based resources, most recently dominated by biofuels. When countries cannot meet these demands domestically, they turn to other countries for resources, especially those with abundant land area, relatively low population density, and weak land governance (Deininger et al. 2011). Rich but resource-poor countries, such as Saudi Arabia, also seek more land to feed and supply resources to their populations.

The international financial crisis in 2008 and the associated food crisis (e.g., hike in food prices) in 2007–2008 played a major role in the recent increase in land deals. These crises have made agricultural land a new strategic asset and an excellent opportunity for investors.[3] Global urban expansion has also played a role in encouraging land deals for two reasons. First, urbanization has significantly reduced the amount of agricultural land available. For example, one to two million hectares of cropland is being converted for housing, industry, infrastructure, and recreation in developing nations each year (Lambin et al. 2003), and this is typically better quality land close to the expanding urban centers. Second, the growing urban population has changing tastes and preferences (e.g., for animal products) and these trends create a belief that land will hold more value in the future (Smaller and Mann 2009), thus prompting investors to take advantage of cheap land in anticipation of higher prices for food and fuel (Anseeuw et al. 2012a).

3 http://www.grain.org/article/entries/93-seized-the-2008-landgrab-for-food-and-financial-security

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International conservation programs may also contribute to production land scarcity and subsequent land deals. For example, as indigenous forests gain new market values from programs such as REDD+ (Reducing Emissions from Deforestation and Forest Degradation in Developing Countries), a source of previously cheaper land for conversion to production is removed from the available supply. Ironically, it is thus also possible to displace indigenous people through land deals in the name of conservation (Lemaitre 2011). This illustrates the complexity of *effects* from telecouplings.

Effects. Land deals are a significant driver of land-use change and of consequential socioeconomic and environmental change. Some researchers argue that land deals provide opportunities to enable land-abundant but otherwise poorer countries to gain investment, employment, and technology (Deininger et al. 2011). Some of the land deals also set aside food produced for local communities or for the domestic market and receiving countries may also invest in the social infrastructure (e.g., hospitals and schools) of sending countries. Others argue that land deals threaten the livelihoods of the rural poor and promote social conflicts; they maintain that land deals could lead to the end of small-scale farming in sending countries, which could compromise local food production, and thus undermine food sovereignty. Land deals also promote an industrial model of agriculture that can lead to more rural poverty, since local job creation in most cases is very low (Deininger et al. 2011).

In terms of environmental effects, there is growing evidence that the land-use changes following land deals can generate large-scale and lasting environmental damage (e.g., loss of biodiversity, soil erosion, and pollution from pesticides and fertilizers) (Deininger et al. 2011). Furthermore, "land grabbing" is also a form of "water grabbing," because much water is embedded in land systems, and changing land use typically alters the use of water (e.g., in many regions, agricultural production accounts for most of the water consumption). The transport of food and fiber from countries that have sold their land titles also represents an export of nutrients. Socioeconomic and environmental consequences of land deals in the sending countries have therefore generated widespread attention in the international news media, which has led to political feedback. As a result, some receiving and sending countries have become more cautious in making new land deals (Agence France-Presse 2012; Perrine et al. 2011).

Insufficient attention has been paid to the net effects of land deals on countries that receive the titles and on spillover countries. For example, it is not clear what the opportunity costs and benefits of these land deals are, how many jobs will be transferred to the sending countries, how much water, fertilizer, and other types of agricultural input (e.g., pesticides) can be saved for the receiving countries, and how much loss of soil nutrients can be avoided. There are arguments that the supply of food and fiber from distant lands to cities in receiving countries in effect "exports" the environmental costs of urbanization.

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The economic and environmental costs (e.g., CO_2 emissions) of transporting goods and people between sending and receiving countries are also poorly documented or understood. As the distances are large and amounts of goods and products are enormous, these costs could be high. Thus the issue of "food miles" and the carbon footprint of food supply has become a major consideration in debates over the sustainability of agriculture.

Laos As an Example

Worldwide, eleven countries, of which Laos is one, collectively account for 70% of the total land targeted in transnational land deals (Anseeuw et al. 2012a). In Laos alone, there have been an estimated 40 land deals involving 140,000 hectares (Anseeuw et al. 2012a). Transnational land deals are a relatively recent phenomenon in Laos, as they did not take place until the early 1990s, due in part to conflicts and political instability (Baird 2011). However, once they began, land deals increased dramatically. Currently 15% of the country's land system is under agri-business concessions (UNDP 2006).

The main *systems* involved are Laos (the sending country) and the investor (receiving) countries, primarily China, Vietnam, and Thailand. Within Laos, farmlands are converted to plantations (mainly for rubber) by investors. Deals were intended to be restricted to state-owned lands, but in practice, private lands have also been affected. Spillover systems include other countries that benefit from the sale of rubber, particularly those in Southeast Asia.

The primary *agents* include investment companies in other countries in Southeast Asia, for example the Asia Tech Company (a Thai firm) and the Dak Lak Rubber Company (from Vietnam). Other agents include the government of Laos, whose early policies opened the way for land to be acquired by foreign investors (Baird 2011), but whose recent crackdowns on overexploitation of the resource and threats to the livelihood of indigenous people have sought to curtail land deals (Agence France-Presse 2012). Local indigenous people in Laos also serve as agents, as they have shifted their livelihood strategies from farming to manual labor on plantations as a result of land deals (Baird 2011).

The main *flows* include money transferred from receiving countries to Laos to secure land, rubber production machines sent to Laos to develop plantations, and the rubber that is subsequently sent to countries all over the world for use in a variety of manufactured goods. Information flows include the land titles granted from Laos and the communications between the sending, receiving, and spillover countries that have interests in rubber development.

The primary *cause* of this telecoupling is economic. Investment companies seek developing countries where there is cheap land available to make profits (Baird 2010). The government of Laos, in turn, viewed the land deals as a means to increase state revenues and improve the country's export market (Baird 2010). Another cause is political: the transition of the political system in Laos from a socialist to a capitalist, market-driven system enabled the land

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deal era to emerge (Baird 2011). Successful implementation of land deals also required a politically stable environment, which was just emerging after decades of conflict at the time when the deals first became prominent.

There are a number of *effects* of this telecoupling. In terms of the natural system, effects range from degradation of ecosystems, loss of biodiversity, to loss of ecosystem services, all of which resulted when large-scale plantations were created on acquired land (Baird 2011). Effects on the human system include increased poverty among indigenous peoples, infringement on their access to natural resources (e.g., water, fodder, and fuel), and erosion of their social structures and family ties due to displacement for wage labor (Baird 2010, 2011). Feedbacks have also occurred between the sending and receiving countries, because the Laos government has instituted new limits and regulations on land deals made with other countries in response to emerging problems (Agence France-Presse 2012).

Implications

The implications of the recent surge in transnational land deals are potentially huge, but remain uncertain. These uncertainties exist because many deals have not been reported, almost half of the reports in the media have not been verified, many of the announced land deals have not been implemented, and there is relatively little empirical evidence of the environmental and socioeconomic effects. For example, a World Bank report found that farming had only begun on lands involved in 21% of the announced deals (Deininger et al. 2011). While the demand for land has been large, some researchers believe that the potential supply is also high. Some estimates suggest that the world still has over 445 million hectares of nonforested, uncultivated land suitable for rainfed cultivation of at least one of the five key crops (wheat, sugarcane, oil palm, maize, and soybean) (Deininger et al. 2011). Thus, the trend of large-scale land deals may continue in the future (Anseeuw et al. 2012a). More research is needed to confirm the actual amount of suitable uncultivated land.

Reducing uncertainties and generating reliable information is essential to understand the implications of land deals. Data on transnational land deals are challenging to obtain and verify (Friis and Reenberg 2010).[4] The Land Matrix Project, an international network of 45 organizations, has been able to establish the largest and most comprehensive database of land deals around the world. However, the data are still far from complete and must be considered conservative since, on one hand, they are mainly based on media reports and, on the other, many land deals have not even been reported in the media (Anseeuw et al. 2012a). Furthermore, even for deals recorded in the database, many of the details are unknown (e.g., size, date of contracts, boundaries), partly because much of the information is regarded as "confidential."

[4] See also the Land Matrix Project at http://landportal.info/landmatrix

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The telecoupling framework contributes a better understanding of this complex global issue to the land-change science community. It provides a means to answer key questions concerning the diverse causes of transnational land deals, the cascading and feedback effects of land deals on food security and land degradation across multiple coupled systems, and the diverse groups of agents involved in land deals, as well as their roles in facilitating flows among the systems. Such an approach is required if different institutions from multiple coupled systems are to work together to address the socioeconomic and environmental challenges that result from land deals.

Species Invasions

Worldwide, the number of invasive species has increased, as has the overall number of species introductions, which have greatly impacted global land use. Species introductions from one region or continent to another can be traced back to at least 1492 CE, corresponding to human exploration of the globe (Hulme 2009). Overall, however, species introductions were limited in scope and impact until around 1800, whereafter they began to increase rapidly due to the effects of the Industrial Revolution, which served as a catalyst for rapid expansion of the global economy (Hulme 2009). For instance, the annual number of introduced species in Europe increased by 300% for plant species and 600% for invertebrates and mammals between 1800–1850 and 1975–2000 (Hulme 2009) (Figure 7.2). Today, there are over 500,000 alien species worldwide—50,000 in the United States alone (Pimentel et al. 2007). A proportion of

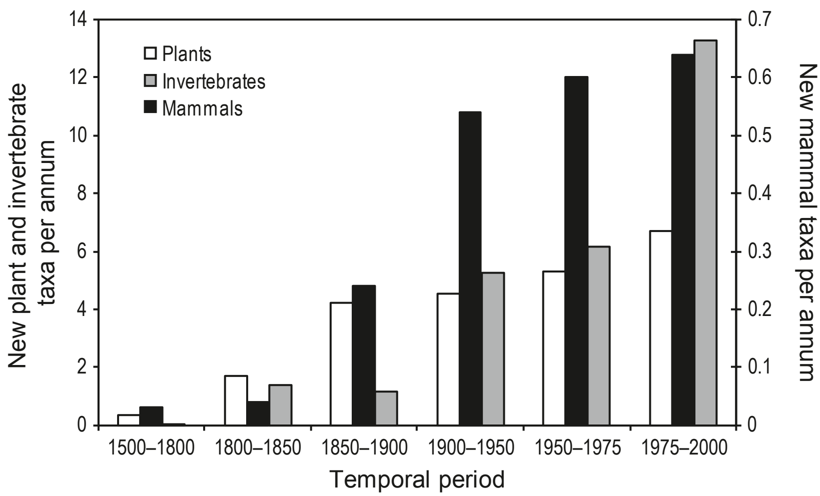

Figure 7.2 Dynamics of introduced plants, mammals, and invertebrates in Europe (after Hulme 2009).

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these species have become invasive, with currently over 9,000 invasive plants and animals officially recorded (Pimentel et al. 2007). Even so, estimates of alien and invasive species are widely believed to be gross underestimates.

Telecoupling Components

Systems. Prior to the nineteenth century, invasive species spread from Europe (sending system) to other parts of the world (receiving systems) through human migration and trade. Over the past two centuries, globalization and associated advancements in trade, travel, and technology have brought invasive species to all corners of the globe. The receiving countries with the highest documented numbers of invasive species are the United States (3379), Australia (419), and New Zealand (410) (Sellers et al. 2010). Islands are at greater risk than large continents, and there is an increase in the number of invading species (per system) from North to South across the globe in the Northern Hemisphere, a sharp drop in the Tropics (where few invasions occur), with invasions then increasing again while moving southward into temperate lands (Vitousek et al. 1997).

Agents. Humans are agents of invasive species spread around the world, as they facilitate spread through travel, migration, and transport of goods and products. Human agency includes both production (e.g., the introduction of new species for agriculture or forestry) and consumption (e.g., the purchase of imported plants and animals for food and pleasure, such as gardens and pets). Invasive species themselves can also be considered agents because of their consequential actions. For example, many invasive species cause damage to indigenous ecosystems as a result of different competitive abilities over native species. The Invasive Species Specialist Group list of the 100 most destructive invasive species worldwide includes 36 plants, 26 invertebrates, 14 mammals, 8 fish, 5 fungi, 3 amphibians, 3 birds, 3 microorganisms, and 2 reptiles.[5]

Flows. The main flows involved in species invasions are the transfer of the invasive plants, animals, and microbes themselves. Other material flows include transport of control agents such as pesticides or natural enemies of the invaders. Information flows include the sharing of knowledge across systems on how to control the invaders. Knowledge is also transferred among groups of scientists and agencies when experts in receiving systems seek to understand the behavior of the invasive species in its native habitat (in the sending systems).

Causes. Invasive species may be transported intentionally by humans for the purpose of pet trade, horticulture, farming, or biological control of other

[5] http://www.issg.org/database/species/reference_files/100English.pdf

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organisms. However, the majority of invasive species are spread accidentally by being present in vehicles, ships, and planes. Humans may also make purposeful land-use decisions that directly promote invasive species, even when they are mindful of conservation goals; for example, the recent increase in lands devoted to growing nonnative species of biofuels that display invasive properties in some systems (Danielsen et al. 2009). Land-use change may also create new niches or conditions upon which alien species can capitalize. For instance, land-use changes arising from the increased frequency of forest fires can subsequently promote the invasion of nonnative grass species that may be better adapted to higher frequencies of fire (Vitousek et al. 1997).

Effects. Some introduced species are beneficial for human welfare or ecosystem functioning, especially the crops and livestock that fuel agricultural economies worldwide, which are over 99% nonnative (Pimentel 2002). However, a large number of invasive species have had widespread and pernicious effects, such as the extinction of native species. As much as 80% of the world's endangered species have been threatened (Mooney and Cleland 2001; Wilcove et al. 1998; Armstrong 1995), through the collapse of whole animal and plant communities (Sanders et al. 2003) and through the disruption of large-scale ecosystem processes (Gordon 1998).

Species invasions are also a major cause of global land-use change and economic losses. Invasive species can directly bring about such changes by converting one land-cover type to another: invading trees convert grasslands to forests and invading grasses convert bare lands (that may have previously been forest) to grasslands. In addition, invasive species may indirectly cause land-use change. For instance, the Eurasian cheatgrass changed the fire frequency of shrub/steppe habitat in the Great Basin of North America from once every 60–110 years to once every 3–5 years, and then subsequently outcompeted local grasses not adapted to that fire cycle to take over five million hectares of land (Vitousek et al. 1997). The economic costs of invasive species are enormous (Figure 7.3). For example, the gypsy moth (a nonnative pest that originated from France) was transplanted to an urban forest in the eastern United States (Vitousek et al. 1997), where it has infected over 190 million acres of natural forest, requiring millions of dollars annually to manage (Mayo et al. 2003).

Besides receiving and spillover systems, invasive species may also affect the sending systems—feedbacks that are rarely discussed in the literature. Sending systems may gain benefits from selling invasive species or engaging in trade with other countries; this inadvertently results in invasive species spread. Sending systems may also incur costs due to invasive species prevention and control policies. Negative impacts on sending systems could occur if sending systems outlaw or issue fines within their own country or receiving systems implement international invasive species tariffs on sending countries to punish them (Touza et al. 2007).

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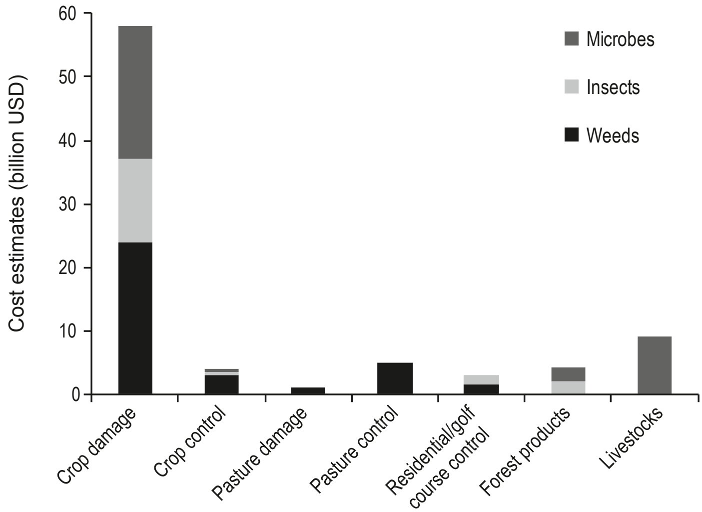

Figure 7.3 Conservative cost estimates of introduced weeds, insects, and microbes to select sectors of the U.S. economy (based on data from Pimentel et al. 2005).

Cheatgrass (Bromus tectorum) As an Example

Cheatgrass is an annual bunchgrass species native to Central Europe, southwestern Asia, and northern Africa. The species was accidentally introduced from Central Europe to numerous shrub-steppe ecosystems all over the globe via agricultural grain exports, contaminated packaging materials, and contaminated ship ballasts on ships in the 1800s. It was first discovered in the United States in the mid 1800s (Klemmedson and Smith 1964), and by the early 1990s it could be found throughout its current range. This species has the potential to alter entire ecosystems by outcompeting native species and has caused considerable damage to agricultural production systems (Knapp 1996).

The *systems* involved are countries in Central Europe (sending systems) and Russia, countries in Western and Central Asia, Japan, South Africa, Australia, New Zealand, Iceland, Greenland, Canada, and the United States (receiving systems).[6] Areas within the receiving countries that are affected include (a) sagebrush grasslands, particularly those that are already disturbed by human impacts which promote increased direct sunlight exposure (e.g., grazing, cultivation, frequent burning), (b) human-managed rangelands and pastures, and (c) wasteland and barren environments. Since cheatgrass invasions (and associated fire events and conversion of shrublands to grasslands) have had profound impacts on the global carbon balance, and have both contributed to and are affected by global warming, spillover systems include countries around the entire globe.

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6 Global Invasive Species Database (IUCN) at http://www.issg.org/database/welcome/

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The main *agents* involved are the human traders, who inadvertently transported the grass seeds on ships, and farmers, who received the grass seeds embedded in agricultural imports. A number of agents have been involved in efforts to curb invasion, including livestock herders, farmers, fire control operators, and government agencies. Agents that have unknowingly contributed to invasive species spread are land users that degrade rangelands due to overuse (e.g., overgrazing), thus making them more vulnerable to invaders, as well as humans and animals that move long distances and can transport the seeds via their clothing and fur.

The main *flows* include the transport of the grass seeds themselves, in addition to information flow among different agents about techniques to control the spread of the grass (e.g., hand pulling, introducing grazing animals to suppress the grass, reseeding of native perennials, herbicide application, prescribed fire). Materials used for invasive species control (e.g., native seeds) are also transported among systems. Carbon may also flow into the atmosphere from receiving to spillover systems through cheatgrass conversion of shrubland to grassland and via fire events promoted by cheatgrass.

The initial *cause* of cheatgrass invasion was accidental—a result of global trade via ships in the 1800s. Subsequent spreading occurred when seeds were transferred on animal fur or human clothing, along roads and railways, or via wind. Successful establishment after spreading has been made possible by the competitive abilities of the species (i.e., their ability to monopolize available soil moisture at the expense of other plants through an extensive root system) and the species' resilience in disturbed environments (D'Antonio and Vitousek 1992). Humans have also promoted the spread of the invasive species through, for example, the practice of intensive grazing of livestock on rangelands in the Intermountain West of the United States, which depleted native grass species, thus paving the way for an explosion in the cheatgrass population (Mack 1981).

The *effects* of cheatgrass invasion are widespread and include reduction of biodiversity, destruction of habitat for wildlife, and destruction of agricultural crops (and resultant loss of income). For example, there is currently an estimated 31.5 million acres of cheatgrass in the Great Basin of the United States, where native species once dominated (Menakis et al. 2003). Cascading effects include the propensity of cheatgrass to increase the frequency of fires in habitats that it occupies, which can decrease soil nutrients. Managing for cheatgrass-caused fires in the Great Basin alone is estimated to cost nearly USD 10 million per year (Knapp 1996). Feedback effects occur between receiving, sending, and spillover systems as a result of global climate change due to CO_2 emissions from cheatgrass invasion. For instance, in the Great Basin of the United States alone, cheatgrass invasion has released 8 ± 3 Tg of carbon into the atmosphere (spilling over across the globe), and will likely release another 50 ± 20 Tg C over the next few decades (Bradley et al. 2006). Global climate change caused by cheatgrass invasion, in turn,

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affects further spread of the cheatgrass into new areas, because cheatgrass is sensitive to changing precipitation regimes and is predicted to shift its range dramatically to areas that receive lower precipitation under global climate-change scenarios.

Implications

The need for advances in predicting and managing invasive species is urgent, considering that one of the most critical aspects of invasive species biology is that there are significant time lags before the consequences of species introductions are detected on the landscape (Crooks and Soule 1999). In other words, the currently observed effects of invasive species may only make up a fraction of all long-term effects that may arise from telecouplings. For instance, the effects of the exponential increases in imports and exports from China on the country's invasive species load have not yet been fully realized and may not emerge for years (Jenkins and Mooney 2006).

Despite extensive research on invasive species, significant challenges remain in predicting the spread of invasive species and the management of invaded systems. Conceptualizing species invasion as a telecoupling can help propel this field forward, as it identifies how invasive species are linked in sending, receiving, and spillover systems. The telecoupling framework addresses these urgent needs in the context of land-change science by explicitly characterizing the relationship between the distant coupled systems involved. In addition, it addresses key questions:

- How do diverse agents change their behavior over time and space in response to an emerging invasion?
- How do flows of invasive species and control methods interact with one another across systems (including spillover systems)?
- How does the invasion create cascading effects that are not limited to a single system?
- How can the causes of invasion originate from multiple, different systems and at a global level?

The framework also provides a mechanism to address future policies on the control of invasive species spread, which requires collaboration between institutions from multiple coupled systems. Telecoupling allows for explicit characterization of how species invasions relate to other aspects of complex coupled systems, particularly those relating to dynamics in global human systems (e.g., socioeconomic and institutional drivers of trade and migration patterns). Species invasions are also closely related to other telecouplings, such as trade, since countries with higher rates of international trade experience higher rates of species invasions (Westphal et al. 2008) due to increased opportunities for species to be transported (either purposefully or accidentally) along with trade goods.

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Challenges, Opportunities, and New Directions

Telecouplings offer new and unique challenges and opportunities for the land-change science community. As illustrated in the framework and the examples above, telecouplings are more complex than local couplings because the former involves multiple places, multiple flows, multiple agents, global causes, and global effects. Many crucial and complex questions can be addressed using the telecoupling framework. One question is how feedbacks between multiple coupled systems connect and propagate the effects of telecoupling widely across space. Another key question is what role spillover systems play in the telecoupled system. These spillover systems are rarely considered explicitly and have not even been recognized in previous research or management. The effects of telecoupling on spillover systems may sometimes exceed those on receiving and sending systems, as demonstrated particularly in the invasive species example.

Another major implication of understanding telecouplings is governance. Telecouplings create more challenges and complications for management and policy than local couplings. Because sending, receiving, and spillover systems are far removed from one another (and typically in different jurisdictions), the conditions within different parts of the telecoupled system are beyond the control of any single government or management agency. Managing one telecoupling is not easy, but managing multiple telecouplings simultaneously is a significant challenge for land-change governance (Table 7.1), as they may amplify or offset each other. Some international policies, such as the REDD program to combat deforestation, seek to manage the effects of telecouplings. However these endeavors have focused largely on individual telecouplings and have not fully considered the interactions of multiple telecouplings; they also have not considered the spillover effects in a systematic fashion or at all. Another challenge is how to manage the relationships between telecouplings and local couplings. For example, although there has been a push for consuming locally produced products (Desrochers and Shimizu 2012; MacMillan 2012), the increased trends brought about by telecouplings are difficult to reverse. Thus, current land-use policy and stewardship approaches which only consider local couplings need to adopt a new or revised structure that fully integrates telecouplings so that, in turn, positive effects can be enhanced and negative effects reduced with respect to sustainability.

A key issue to address in research and management is the data needed to characterize telecoupled systems. As shown in the examples above, huge data gaps exist in all telecoupling components. Thus far, work on telecouplings has focused on virtual resources used (e.g., virtual water, virtual land). For example, China is in the top ten countries engaged in the virtual trade of water (a global market involving a total of 625×10^9 m^3 of water exchanged around the globe per year) (Konar et al. 2011). Obtaining relevant data on telecouplings is more complicated, more time-consuming, and more costly than research on

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local couplings alone. This is because various systems (sending, receiving, and spillover) are in distant places and usually under different types of governance. As many driving forces originate from outside a coupled system and are difficult to predict, it is sometimes challenging to determine what kinds of data to collect and where to collect in advance.

It is encouraging, however, that new opportunities to address telecouplings are emerging. More researchers are realizing the need to address telecouplings in relation to global land use. More advanced tools for collecting, analyzing, and visualizing data are becoming available. For example, value-chain analysis, GPS collars, genetic markers, and barcodes are being used to track the long-distance movement of organisms, goods, and products. In the future, a relational database approach could be very useful for stimulating data organization and integrated analysis of telecouplings. For instance, information about transnational land deals could be entered into a relational database with a list of systems (sending, receiving, and spillover); each system would include a list of agents; each agent a list of other systems and deals in which the agent has also been active; each flow would include links to different systems and list each cause and effect that is related to each system. This could be linked with data about another telecoupling, say species invasion, thus providing insights into the relative complexity and interconnectedness of agents and systems involved in different types of telecouplings. Such an integrated analysis can help identify the types and interrelationships of telecouplings that have potential for the greatest socioeconomic and environmental impacts.

Rethinking and reexamining land-use dynamics in the context of telecouplings, therefore, requires new directions to be pursued in land-use change research. These may include (a) changes in the conceptual frameworks of land use, from a focus only on local couplings, to a combination of local couplings and telecouplings, (b) changes in research paradigms from site-specific and multisite comparisons to multisite linkages, and (c) changes from collaboration and dialog within the land-change science community to networking with experts in other disciplines and with various stakeholders around the world (e.g., the media and nongovernmental organizations, such as a Land Matrix for transnational land deals).

Conclusion

The telecoupling framework offers a useful analytical approach to integrate distant forces of land-use change across the globe. In the framework, agents, flows, causes, and effects as well as their relationships across multiple coupled systems are conceptualized as part of a broader telecoupled human-natural system. The examples provided in this chapter demonstrate the utility of the framework. Transnational land deals and species invasions vary considerably in terms of systems, agents, flows, causes, and effects, yet the framework

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consistently captured and connected all major relevant issues in both cases. Thus, the telecoupling framework can help researchers systematically analyze each of the system components and their relationships with one another.

Understanding telecouplings has enormous implications for managing and governing global land use at a time when the land-change science community faces unprecedented challenges and opportunities. New research directions are needed to meet the challenges of stronger and more widespread distant forces that drive land-use change around the world.

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