Supporting Online Material for

Complexity of Coupled Human and Natural Systems

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Supporting Online Material

Table S1. Selected attributes of six coupled human and natural systems in Africa, Asia, Europe, North America, and South America. All these studies but one (Kristianstads Vattenrike of Sweden, led by Carl Folke) were funded under the program on "Dynamics of Coupled Natural and Human Systems" of the U.S. National Science Foundation. The lead principal investigators for these studies are Marina Alberti (Central Puget Sound, Seattle, USA), Stephen Carpenter (Northern Highland Lake District, Wisconsin, USA), Jianguo Liu (Wolong Nature Reserve, China), Emilio Moran and Elinor Ostrom (Altamira, Brazil), and Alice Pell (Kenyan Highlands, Kenya). The information in the text and in this table is extracted from these projects unless indicated otherwise.

Characteristics	**Kenyan Highlands, Kenya** (*S1*)	**Wolong Nature Reserve, China**	**Kristianstads Vattenrike, Sweden** (*S2*)
Location	The coupled human and natural system is located in two regions of the Kenyan highlands: 1) Embu district in Eastern Province and 2) Vihiga district in Western Province. The coordinates for central locations in each of the districts are: Vihiga: 0° - 0° 15' N and 34°30' - 35° and Embu: 0.30°S 37.30°E.	Wolong is located in Sichuan Province, southwestern China ($102^0$52' and $103^0$24' E, and $30^0$45' and $31^0$25' N).	Southern Sweden, in the county Scania, and in a culturally shaped landscape. Latitude 60° N and longitude 15°W.
Human population	The population of Vihiga district in 1999 was 498,883 people. Embu district had 278,196 people.	As of 2005, Wolong has more than 4,500 local residents in approximately 1,100 households.	About 76,000 people in the municipality (56 inhabitants per km^2).
Spatial extent	The two districts include 1,292 km^2.	2,000 km^2	1,100 km^2 within the Municipality of Kristianstad (1,346 km^2)
Characterization of ecological system	These two areas represent much of the Kenyan highlands where the altitude is > 1500 masl (meters above sea level) and rainfall is ~1200 mm/year, an area of approximately 32,400 km^2 or 5.7% of Kenya's area. The soils in Vihiga are clayey loams (ferrosols and acrisols) while those in Embu are mainly well-drained nitosols of volcanic origin. The	Wolong is famous for its bamboo forests – forests with understory bamboo species. It contains several forest types along elevation gradients: evergreen forest, mixed evergreen and deciduous broadleaf forests, mixed conifer and deciduous forests, and conifer forests. Elevation ranges from 1200 to 6250 m and above 3400 m, there are meadows,	A wetland and fertile agricultural landscape with forest patches in a semi-urban river basin subject to floods and the city of Kristianstad at and below sea level with some protective structures in place.

	Embu soils are inherently slightly more fertile than those in Vihiga District.	rocks, and snow cover.	
Ecosystem services	Agricultural and forest products (maize, tea, coffee, milk, vegetables); tourism; wildlife; water	Forest products; non-harvest recreation; Chinese herbal medicine; pandas and several thousand other species; freshwater, hydro-power; limited agriculture. It is also a UNESCO Man and Biosphere (MAB) Reserve and World Heritage Site.	The ecosystem services (food production, nutrient filtering to the coastal area, recreational values, biological diversity, cultural heritage) are related to cultivation of land and annual floods, and are sustained by a large network of local steward associations. It is a Ramsar site and was recently made a UNESCO Man and Biosphere (MAB) Reserve.
Characterization of economic system	Agriculture is the predominant industry in both districts, but 27% of income comes from off-farm sources in Embu. Although the transportation infrastructure is not adequate in either district, especially on secondary roads, Embu's proximity to Nairobi provides significant economic advantages. Although Vihiga is about the same distance from Kisumu, Kenya's third largest city, Nairobi provides significantly stronger markets and employment opportunities. An important difference between the two districts is the amount of agricultural diversity: in Vihiga district, maize (corn) and beans are dominant with small amounts of tea, while in Embu**,** farmers produce milk, green beans, tea, coffee, passion fruit, potatoes, macademia nuts and avocadoes in addition to staple foods.	Local residents rely mainly on agriculture (growing corn, potato, and vegetables for subsistence) and use fuelwood as their main energy source for cooking and heating in winter. In addition, almost all households raise pigs. Some residents also collect Chinese medicinal herbs, provide transportation services, construct local roads, and work in cities as temporary laborers. Recently, tourism is becoming more popular in Wolong (about 200,000 tourists in 2005 from China and other countries) and some local residents earn income through selling products to tourists and working in the tourism industry.	The area is the bread basket of Sweden with agricultural produce, including livestock, fruits and vegetables. Many small enterprises in the retail business are linked to the food sector, including organic farming, top restaurants, fairs, marketing high quality food and a well-developed tourist industry and service industry.
Characterization of political and administrative institutions	Both districts are subject to the national government (a parliamentary democracy largely based on the British system) with 7 provinces that are divided into 63 districts.	Wolong is managed by Wolong Nature Reserve Administration, which reports to China's State Forestry Administration and Sichuan Forestry Department. Within Wolong, there are two townships that each consists of three villages.	Democracy, with a diversity of political parties from the national all the way down to the municipal level. Diversity of local groups like farmers, firms, and NGOs coordinated by the bridging organization the Biosphere Office (previously Ecomuseum) that is embedded in the Municipality of Kristianstad. Flexible local management in multilevel

			governance from local to county with links to national levels and part of the international Man and the Biosphere framework of UNESCO.
Characterization of culture	Most of the residents of Madzuu Village are Luhyas (Maragolis) while most living in Embu are Embus.	Wolong is dominated by minority culture (about 70% of local residents are Tibetans).	Many local steward associations that are linked with businesses, NGO's and municipalities, as well as county, national and international levels of governance of the landscape. Over 80% of the human population was born in Sweden, 9% in the rest of Europe and 8% outside Europe.
Environmental problems	Soil degradation is the most pressing problem. Because of the high cost of fertilizer and double-cropping of maize, mining of soil nutrients is common, resulting in sharply reduced crop yields.	The reserve was established in 1975 to protect habitat for the world-famous endangered giant pandas (and approximately six thousand other animal and plant species), but human activities have degraded the habitat through forest harvesting and land conversion (*S3*). The government has recently implemented three conservation programs to protect and restore the habitat (natural forest conservation program to prevent illegal forest harvesting, grain-to-green program to return cropland to forested land, and eco-hydropower plant to provide electricity for local residents to reduce fuelwood consumption) (*S4*).	The major issues are risk of flooding, possible river eutrophication, degradation of wetlands and marshes and with it loss of flora and fauna, and the sensitive and highly connected freshwater/groundwater systems of the area. Major responses include restoration, a shift in vision and policy of the whole region towards ecological understanding and associated social structures to deal with ecosystem services and change.
Tools and Methods	Tools and techniques consist of field observation, household surveys, and computer model using systems dynamics approach that that includes the complex feedback loops among economic (conditioned by sociological constraints), livestock, crop, and soils submodels. The team's social science methods have included survey data with similar surveys administered in 1989 and 2002 in western Kenya. There is nothing especially	Tools and techniques include field observation, socioeconomic survey instruments (e.g., structured, semi-structured, and unstructured interviews with key informants), neighborhood history calendars, interviews with focus groups, use of census data and government documents, remote sensing techniques, global positioning systems, geographic information systems, spatial databases, discrete choice modeling,	A spectrum of interview techniques (both quantitative and qualitative methods) about management practices include assessment of biological and ecological knowledge, social processes like collaboration, social networks, knowledge generation, agents and leadership, structures of multilevel governance. These are examples of empirical studies based on field work of social features behind ecosystem management often involving in-depth semi-structured interviews with key informants

	novel about the surveys or ways in which they were administered in the socio-economic survey. What is much more innovative is that the research team had good socioeconomic data over a 13 year period and comprehensive data on soil fertility, crop yields and farmers' attitudes.	spatial statistics, and computer modeling and simulation (e.g., agent-based models, Monte Carlo simulation) (*S5*) (*S6, S7*).	identified through pilot studies. Sources of written information like municipal protocols, inventories, maps, correspondence, Internet sites, media clippings were used as complementary information and also for triangulation of the results (*S2, S8*).
Unanswered questions	More work is needed on the nature of soil degradation and poverty traps. In particular, what is needed to permit people to escape from poverty traps and what is needed to prevent people from falling into poverty? For rural populations, economic and environmental health is inextricably linked but the research team does not fully understand these relationships.	How much influence do cross-boundary interactions (e.g., temporary laborers from Wolong to cities, and tourists from cities to Wolong) have on ecological and socioeconomic patterns and processes in Wolong?	To what extent is the multilevel governance system not just adapting in the short term but actually contributing to long-term sustainability of the social-ecological system? What are the features that make such long-term adaptation possible? What are the barriers? What are the strategies for living with uncertainty and surprise (see, e.g. (*S8, S9*)).
Technical challenges	Soil repletion is a slow process and data that show the shape of how quickly soils can be restored are lacking, particularly for soil organic matter. Similarly, poverty is dynamic so that obtaining sufficient data over a 20-25 year time frame is difficult. Finding ways to replete degraded soils quickly in the current environment in which fertilizer subsidies are out of favor is difficult.	Remote sensing data with higher spectral and spatial resolution are needed to detect small changes over short periods of time across the entire reserve. The changes in vegetation due to the recent grain-to-green program and natural forest conservation program can be found in the field, but cannot be detected from remote sensing imagery (e.g., Landsat data) during the first several years after the programs were implemented.	Flood protection and improved use of information technology as a means for ecosystem management including zoning, monitoring, communication and collaboration.
Applications to other coupled human and natural systems	The research tem is applying a similar approach to a water and sanitation project in Niger, Ghana and Mali to better understand the economic contributions of livestock.	The fact that the number of households increased faster than human population size in Wolong over the last three decades led to the discovery that this trend is similar globally and it is particularly profound in the 76 countries with biodiversity hotspots (*S10*). Ideas from research in WOLONG NATURE RESERVE have been applied to evaluate	The research has inspired work on identifying transformations of the Great Barrier Reef governance system of Australia and the research team currently collaborates with Australian researchers on those issues.

		the household and population perspective for global biodiversity conservation (*S11*) and to develop conservation strategies for the entire nature reserve system (more than 2000 nature reserves) in China (*S12*).	
Prospect of coupled human and natural systems	It is very hard to judge at this time. It is possible that the Gates Foundation and other development groups will figure out how to jump start agricultural development, which, in turn, will stimulate non-agricultural growth. However, problems of health (HIV-AIDs, malaria and tuberculosis), limited education, poor governance and inadequate infrastructure must be overcome.	The natural forest conservation program and grain-to-grain program are going well. Trees are rarely harvested illegally and more than 400 ha of cropland has been reforested. Natural forests are recovering gradually. Although plantation areas may not be suitable as panda habitat for many decades to come, they may provide alternative fuelwood for local residents and thus reduce pressure on natural forests. Also, the number of local residents working in cities as temporary laborers has been increasing and thus may reduce the demand for fuelwood because they consume less fuelwood in Wolong and their remittances to their families in Wolong afford the use of more electricity. However, tourism has been booming in the recent years and the number of tourists continues to climb (about 200,000 in 2005). Many tourist facilities (including roads, restaurants, and hotels) have been and are still being built to meet the rising tourist demand, which could cause large negative impacts on pandas. In addition, climate change could affect panda habitat in various ways.	The research team believes that the coupled human and natural system has increased its resilience by building adaptive capacity. More leadership and actor group diversity has developed with both horizontal and vertical networks and collaborations, which seem to make the multilevel governance system and the capacity of the landscape to generate ecosystem services less vulnerable to shocks and surprises.

Table S1 (continued…)

Characteristics	**Northern Highland Lake District (Wisconsin), USA** (*S13*)	**Central Puget Sound (Seattle), USA**	**Altamira, Brazil**
Location	Northern Wisconsin and part of the Upper Peninsula of Michigan, USA. Centered on Vilas County, Wisconsin, and with portions of Forest, Iron, Oneida, and Price Counties, Wisconsin, and Gogebic County, Michigan. Roughly 90°W longitude, 46°N latitude.	The Central Puget Sound Region is located in Washington State and includes four Counties (Snohomish, King, Kitsap and Pierce Counties), 5 Central Cities (Seattle, Bellevue, Tacoma, Everett, and Bremerton). Lat and Long Upper Left: (48.29, -123.02) Upper Right: (48.29, -120.90) Lower Left: (46.72, -123.02) Lower Right: (46.72, -120.90)	The study site is located along the trans Amazon highway to the west of Altamira, Para, Brazil. The properties lie along the main trans Amazon highway and the side roads that can be found along the highway about every 5 km, starting about 19 km. west of Altamira and ending about 145 km. west of the city. Latitude 3^{o}S, Longitude 52^{o}W.
Human population	Roughly 65,000 permanent residents in 2000 census. The population is estimated to be more than twice this number during June-August, and during some weekends during autumn color, hunting seasons, and winter sports seasons.	The population of central Puget Sound is currently approximately 3.46 million. Regional average household size dropped from 3.04 persons per household in 1960 to 2.49 in 2000 (*S14*).	About 22,000 people in year 2005, 3916 properties, with an average of more than one household per property. The area is settled at very low density, about 3.7 persons per sq km. Fertility is low, at 2.3 children per woman and still dropping.
Spatial extent	More than 5,300 km^2, 13% of which is lake surface	The region covers (16,291 km^2) (*S15*).	403,676 ha, or 4,037 sq km
Characterization of ecological system	The system is the headwaters of three major freshwater systems: the Wisconsin River, the St. Croix River, and Lake Superior. It has distinctive ecological features, primarily the lakes and the ancestral forests of gigantic white pine. The pineries are almost entirely harvested and have been replaced by younger, second-growth conifer-hardwood forest. The research team chose the boundaries of the system to surround the lake-rich landscape, which is clearly visible from satellite. The boundaries do not correspond to a single watershed or political	In the Puget Sound watershed as a whole, the predominant land cover is overwhelmingly forest, while timber harvest is the dominant land use activity. The mainstem rivers that drain this landscape extend from the rugged unpopulated crests of the Cascade Range and Olympic Mountains down to the rapidly urbanizing lowlands of Puget Sound. Many of their individual tributaries, however, are fully contained within the gentle topography of the Puget lowland. Over that last century those smaller tributaries have been subjected first to logging, then agriculture, and now increasingly to urban development. For a large majority of these sub-watersheds, suburban, and urban	Prior to colonization, the area could be classified as tropical moist forest with a wet season running from about December to May (with rainfall peak in March) and a dry season running from June to November The region has an average annual temperature of 26^{o}C and little variation in mean monthly temperatures+2^{o}C. The topography of the area is quite variable, with steep slopes in some areas. Soils in the region also vary, but contain oxisols, ultisols, and alfisols. Soils in the region display considerable variation in fertility.

	jurisdiction. However, they do correspond to a particular set of ecological and social processes centered on lakes. While the precise geographic boundaries are somewhat arbitrary, they do envelope a region with distinctive processes that can be studied as an open coupled human and natural system. The coupled system contains thousands of natural lakes that together comprise over 13% of the region. Most lakes in this area are clear, with low amounts of nutrients.	development is now the dominant land use.	Although low fertility oxisols are the most abundant soil type in the region, there are also significant patches of medium and high fertility soils. Prior to colonization, forest cover varied across the study region, containing mature upland forest and vine forest. Since colonization, much of the land has been converted to agricultural land uses (60%). On many properties, the original forest cover has been completely removed. Because farmers tend to clear their properties starting at the road and moving to the back of the property, in more recently colonized areas, a strip of forest may still be found between the side roads at the backs of the properties.
Ecosystem services	Fresh water; forest products; fish and game; non-harvest recreation; cranberries and limited agriculture; carbon sequestration	Urban services (water and energy supplies, wastewater treatment, solid waste management, food production and distribution); forest products, agriculture, recreation	Forest products, fresh water, agricultural products, fish and game
Characterization of economic system	The economy depends heavily on tourism and forest products, primarily fast-rotation tree crops for paper pulp. There is some expansion of the service sector, and the internet is enabling more people to maintain dual residences in the coupled system and urban areas of Minneapolis/Saint Paul, Milwaukee or Chicago. Development in this area is primarily along lakeshores. Historically, the Northern Highlands Lake District was first used for hunting and gathering following the arrival of Native Americans, followed by the fur trade in the 1800's and timber extraction that	Economic and employment growth drives population trends and urbanization patterns. There are aproximately1.9 million jobs currently in Central Puget Sound. The regional economy has expanded faster than the national economy. The Puget Sound Regional Council (PSRC) projects that the region will reach 2.0 million jobs by 2010, 2.2 million jobs by 2020, and more than 2.5 million jobs by 2030. The economy is shifting from a manufacturing base to dominance by service and office industries include software, retail, biotechnology, tourism, Internet services, and telecommunications. The proportion of the region's jobs in the manufacturing sector fell from 23.8 percent to 12.4 percent (-11.4 percent)	This is a mixed agricultural area, comprised of household farms on properties averaging about 100 ha in size. These household farms produce a variety of agricultural products including, cattle, cocoa, sugar cane, black pepper (not much any more), maize, beans, and rice. Logging has been increasing in recent years at a rapid rate. Cattle ranching has been expanding and land consolidation has begun to take place to accommodate this expansion in the area in pasture, and declining fertility of some of the soils. New areas are also being opened to settlement and migrants are

	ended in the 1920's. From the 1920's onward it has been viewed as pristine wilderness and management has focused on protection of the natural resources and promotion of the region as a "wilderness" tourist destination. On reservation, the tribal economy is anchored by the Lac du Flambeau casino and growing ethno-tourism (e.g. (*S16*)). Important regional actors include various natural resources agencies, Native American Tribes, other property owners, participants in outdoor recreation, and various groups, such as realtors, construction companies, and tourism operators, that encourage economic development. However lakeshore development for tourism and second homes is increasingly altering the regions' lake ecosystems, which are the region's chief attraction.	from 1960 to 2000, while the FIRES sector (Financial, Insurance, Real Estate and Services) rose from 17.9 percent to 36.3 percent (+18.4 percent).	occupying these areas, sometimes leaving areas fully or mostly deforested, and with worn out soils.
Characterization of political and administrative institutions	The State of Wisconsin through the Wisconsin Department of Natural Resources (WDNR) administers fish and game laws, forest management laws, State Forests, State Parks, State Conservation lands, and administers environmental regulations (many of these mandated by the federal government) Counties administer infrastructure such as roads, utilities and schools. Counties also develop and enforce local zoning laws. Counties also develop have developed lake use plans for waters in their area.	Growth management in Washington State is regulated under the Growth Management Act (GMA) passed by the Legislature in 1990. The GMA requires that cities and counties develop and adopt comprehensive plans and delineate urban growth boundaries and critical areas. Other relevant legislation includes the Shoreline Management Act which requires cities and counties to adopt shoreline management plans to govern shoreline use, environmental protection and public access. While cities and counties have a primary role in governing urban development, The Puget Sound Regional Council plays an important role as a forum for developing policies and making	There is only in recent years the start of effective social movements and the organization of community institutions to provide services of interest to the population. For the first three decades of settlement things were very individual and a lot of dependence on the federal government characterized social organization. There is a large number of formal organizations who try to serve the farmers, closest to them is the extension service, EMATER, which unfortunately is understaffed and

	Tribal institutions (Great Lakes Tribal Council, Great Lakes Indian Fish and Wildlife Commission (GLIFWC), Lac du Flambeau nation) administer tribal lands and natural resources, economic development initiatives, the casino, and schools. Lake Associations or Lake Districts can be organized by lake shore property owners to address commons issues for a given lake. There were 52 Lake Associations in Vilas County in 2002 and there are more than 120 in 2006, indicating a rapid growth in this area. Lakes may have both voluntary (Lake Association) and public management organizations (Lake Districts). Lake Districts are formed when lake area owners formally establish themselves with a local government body such as town, city or village boards. They have taxing authority, elections and some capabilities to regulate lake use. Lake Associations are voluntary organizations with a diverse range of approaches to address lake issues, but do not have taxing authority or power over lake uses. Unlike lake districts, lake associations are often able to act quickly without time consuming government processes.	decisions about regional growth management, economic, and transportation issues in the four-county central Puget Sound region. PSRC is an association of cities, towns, counties, ports, and state agencies that serves (required for receiving federal transportation funds), The PSRC's members include four counties (King, Kitsap, Pierce and Snohomish) and 70 of the region's 82 cities and towns. Statutory members include the three port authorities of Everett, Seattle, and Tacoma, the Washington State Department of Transportation, and the Washington Transportation Commission. In addition, a memorandum of understanding with the region's six transit agencies outlines their participation in the PSRC. Associate members include the Puyallup Tribe of Indians and the Tulalip Tribes, the Port of Bremerton, Island County, and the Thurston Regional Planning Council.	under-funded. There is a very active NGO social movement, particularly the Foundation for Preserving, Producing and Conserving which works directly with farmers and government in developing programs that can provide income, housing, and production assistance. They have also lobbied for protected areas with some success. Most organizations present are not adequately staffed to provide many services to farmers at the farm gate. Farmers must come to them for assistance, and even then their assistance is often late in coming, if at all.
Characterization of culture	Major actors in the culture include: (i) local, off-reservation people whose livelihoods depend on small businesses in the area, many of which are related to	There is great variability in culture across an urban to rural gradient in Central Puget Sound. The population of the region has a median age (36.7 years) slightly higher than in the U.S.	In this frontier people from all over Brazil settled and brought a variety of traditions to the area, but Brazilian culture is pervasive. The settlement

	development, forest products or tourism; (ii) tribal members; (iii) Recreational property owners, generally wealthier people from urban areas (Minneapolis-St. Paul, Chicago, Milwaukee); (iv) Seasonal visitors who do not own property but visit the coupled system for recreation.	overall (36.2 years). Asians constitute a large share of the population (8.2 percent) compared to both Washington (5.5%) and the U.S. (3.6%) African Americans represent 4.9%of Puget Sound's population, compared to 3.2% of the state population and 12.3 % of the U.S. population. Hispanics represent 5.3% compared to 7.5% statewide and 12.5% in the U.S. White Americans represent ~79% of the population of Puget Sound, compared to about 82% in Washington and 75% in the U.S.. The Region's population has a high level of education—40% have post-secondary degrees compared to 36% in Washington and 31% in the U.S. Income levels in the Region are relatively high compared to the U.S. overall—per capita income is over $41,000 compared to $34,000 in the U.S. At the urban end of the spectrum, the population of the Seattle Metro area is relatively young, highly educated and mobile. Seattle households are smaller than those in any other large U.S. city. Net migration is the primary driver behind annual population trends in the region.	cohorts' areas of origin have varied over time, resulting in episodic spurts in given cropping choices (e.g. coffee preference by Parana migrants, cocoa by Bahia migrants, and cattle by Mato Grosso migrants).
Environmental problems	(i) Loss of riparian and shoreline habitat (Degradation of biota, fisheries, sometimes water quality). (ii) Overfishing (Declining size structure and in some cases numbers and species composition of fish caught). (iii) Loss of old growth forest. (iv) Introductions of	In 1999, the federal government listed the Puget Sound Chinook salmon as a threatened species under the Endangered Species Act (ESA). Several initiatives have been taken to implement strategies to reduce impacts on Salmon. There are several specific environmental issues associated with urbanization including forest	The largest problems are the rapid deforestation due to selective logging. Enforcement has been lax and prosecutions rare for clearing more forest than allowed by law. Water sources have dried in some areas where forests were removed near the

	invasive species (Loss of recreational potential, game fish). (5) Eutrophication (Algae blooms, fish kills, health risk).	fragmentation, loss of riparian and shoreline habitat, increased water runoff and release of toxic chemicals and nutrient, and increase in marine biotoxins and pathogens, low oxygen and fish kills.	source of streams.
Tools and methods	Ecological measurements are obtained through field observation and experiments. In terms of social science techniques, the team employs GIS analysis of census data and several different survey instruments. At present the research team is focusing on household-level surveys aimed at understanding decision-making of individual landowners, patterns of landowner decision making across the landscape, and how social interactions among landowners (e.g. through emergence of Lake Associations) influences decision making. The research team also used short courses, workshops, and other outreach activities with local people to help understand the social system of the coupled system.	The research team uses a variety of methods. For analyzing landscape change the team measures land cover composition (i.e. % cover type) and configuration (i.e., aggregation index, mean patch size etc.). The team uses remote sensing to classify satellite data using both supervised classification and spectral unmixing. The team also uses spatial analysis using GIS and landscape metrics (Fragstats) to quantify landscape structure and landscape change. The land cover change component consists of a set of spatially explicit multinomial logit models of site-based land cover transitions. The transition probability equations are estimated empirically as a function of a set of independent variables (including several biophysical and socio-economic variables) comparing land cover data ever two years from 1986 to 2002. The team uses Monte Carlo simulation to determine whether each pixel of a specified land cover changes to another cover type or remains in its current state. The biological diversity component of the project focuses on understanding colonization and extinction of birds in an urbanizing landscape and developing models of changes in bird species composition and relative abundance in response to forest loss. The team chose 139, 1-km^2 study landscapes (*S17*) within a 3,200 km^2 area of temperate, moist forest around Seattle, Washington. Each study site included built portions, for a total of 115 single-family residential sites, 14 commercial/industrial sites,	Tools and techniques include field observation, household surveys, remote sensing techniques, global positioning systems, and geographic information systems.

		and 10 forested sites with minimal development. Trained observers conducted fixed-radius (50 m) point count surveys of breeding birds in all landscapes during the spring and summers of 1998 through 2005. The research team conducted 6437 counts at 992 locations within 139 study landscapes between 1998 and 2005. Individual sites were sampled 1-7 years. Locations within sites were visited 3-5 times per year (late March – late August). The impact of land cover on human preference and residential location choice was conducted using hedonic regression models of residential property values. The research team regressed real estate prices against a set of structural attributes (those intrinsic to the house and lot regardless of location) spatial attributes (attributes of the surroundings neighborhood), and environmental factors (% forest cover).	
Unanswered questions	There is a tendency to model socio-ecological systems with humans as a single entity, like any other population. But the differences among people lead to different choices and behaviors and these differences of choices/behaviors lead to very different ecological outcomes than one would find were everyone to have the same preferences over environmental goods and services. The Beard, Cox and Carpenter study (*S 18*) is along this line –when it comes to fishing, a handful of individuals behave differently from the rest, and this difference explains why there is not tremendous variation in fishing quality across lakes. These differences also have profound repercussions for the economics of public policy, e.g., a "one	The research team is working on a number of experiments that targets specific types of coupling and feedback mechanisms between human decisions and biophysical processes. The team aims to represent more explicitly human and natural agents and their feedback mechanisms to addresses four questions: i) How do dynamic landscape systems evolve to generate emergent patterns in urban landscapes? ii) What nonlinearities, thresholds, discontinuities, and path dependencies explain divergent trajectories of urban landscapes? iii) How do emergent urban landscape patterns influence biodiversity and ecosystem functioning? and iv) How can planning integrate this knowledge to develop sustainable urban landscape patterns?	The research team continues to try to understand population and environment dynamics, among them why would young women terminate their fertility after two children, in an area where labor is scarce on the farm? Why do they use a permanent and radical solution, rather than one that is reversible? Why does the grid layout persist, despite no formal obstacles to fragmentation and dismemberment of properties? Why do some localities develop self-organizing institutions, and others don't? More research is needed to explore the importance of lot life cycle effects, specifically when they occur and in which types of settlement areas.

	size fits all" approach to shoreline management is not likely to be an economically or politically superior policy. So in a nutshell: an important unanswered question is the heterogeneity in human preferences in the region, and the influence of this heterogeneity on human behavior (broadly defined to include collective action) and ultimately on local ecology. How do the switchpoints in the coupled human and natural system interact? Although dynamics are complex, roughly speaking the research team can study spatial patterns and dynamics using switches (examples: invaded or not invaded by species X, fishless lake or lake with fish, seepage or drainage lake, on the reservation or off the reservation, etc.). How do social switchpoints affect the probability of, and time lag until, future ecological switchpoints? How do ecological switchpoints affect the probability of, and time lag until, future social switchpoints? How are these series of switchpoints affected by gradual exogenous drivers, such as the changing demography of the "source region" for people (Wisconsin, eastern Minnesota, northern Illinois), climate, and so forth?		
Major technical challenges	There are many technical-level issues of measurement, modeling and theory development but these become tractable when people have the time and resources to form the necessary	Some major modeling problems include non-stationarity (spatial and temporal) and spatial dependency. A major challenge is the ability to realistically represent, in a unified modeling system, the complexity of human behaviors	Roads are very poor, and access to area limited to very few months. Because properties are very large in size, to verify the individual properties' boundaries is time

	collaborations and focus together on the problems.	influencing urban development and land cover change as well as the biological responses and feedbacks. These are due to scale mismatch, time lags, and the simultaneity of human and biophysical processes. In addition there is the challenge of developing an integrated spatial database of both socioeconomic and biophysical processes.	consuming and costly. Satellite imagery may not be available for several years running that is cloud free enough to allow examination of study area. Modeling related challenges are associated with the complexity of the biophysical and socio-economic factors influencing household land-use decision making. Validation of spatial output is hampered by household and landscape heterogeneity.
Applications to other coupled human and natural systems	The Lake Futures project (*S19*) was the prototype scenario exercise used to develop approaches for the Millennium Ecosystem Assessment scenarios (*S20*). The Lake Futures approach was used directly in the Caribbean Sea Assessment of MA, for example, and influenced other subglobal assessment projects that used scenarios. The Global Scenarios team used the Lake Futures Project as a "laboratory" to organize the research team's thinking about qualitative scenarios and bridging to models (*S21, S22*). The work in Wisconsin was among the projects that nucleated to form the Resilience Alliance (*S23*), and contributed to the design of the Resilience Assessment and Management (RAM) approach (*S24, S25*) employed by the R.A. in many case studies throughout the world. RAM is a hybrid approach; The research team is one of several contributors to the evolution of the methodology.	The approach developed in the Puget Sound region is now being applied to the Phoenix metropolitan areas to test hypotheses about how the interactions of human agents, real estate markets, built infrastructure, and biophysical factors drive current patterns of development and how these patterns affect human and ecological function in these two different bioregions.	The research team has done considerable comparative work on human dimensions of global change, comparing the study site to some other locations in the US (Indiana), and other countries (*S26*).

Prospect of Coupled Human and Natural Systems	For the region, see the scenarios at (*S19*). Since that project was completed, the region appears to be moving in the direction of the "Northwoods Quilt" scenario.	The Puget Sound Regional Council (PSRC) projects that the region will reach a population of >4.5 million and more than ~2.5 million jobs by 2030. The economy is shifting from a manufacturing base to dominance by service and office industries include software, retail, biotechnology, tourism, Internet services, and telecommunications. The research team's predictions of the impact of these changes on land cover for 2027 based on the team's Land Cover Change Model show a decrease in mature forest types (deciduous, mixed, and coniferous) from 60% of the study area to 38% and an increase in developed land (heavy, medium, and low urban classes) from 17% to 34% of the four county land area.	The area continues to experience deforestation, and regrowth. It seems to have entered a phase of considerable land and property consolidation, near the city of Altamira, with some fragmentation of properties along the front road to provide space for services and businesses. There are new areas of settlement opened up every few years, which start the process again. There is greater institutional response and activity by social movements, and thus one can expect more challenges to illegal logging and other activities. Enforcement has never been good, but there is increasing willingness to consider it. Violence still characterized land conflict in the area, between larger and small settlers, and this results in occasional government interventions. Some areas are being set aside for protection as conservation areas, but whether enforcement of these boundaries can be effective remains to be seen.

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