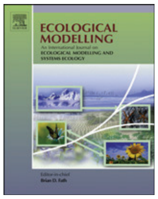
Ecological Modelling 229 (2012) 1–4

Contents lists available at SciVerse ScienceDirect

Ecological Modelling

journal homepage: www.elsevier.com/locate/ecolmodel



Editorial

Understanding human decisions in coupled natural and human systems

1. Introduction

Global human population increased exponentially during the last 200 hundred years (Vitousek, 1994), and very soon the earth will be home to over seven billion people (U.S. Census Bureau, 2011). Human activity reshapes the environment to such a degree that rarely, if ever, do pure or “pristine” ecosystems remain immune from human impact (Dompka, 1996; Vitousek et al., 1997). Humans appropriate up to 40% of the photosynthetic output of the planet for food and material consumption (Haberl et al., 2004) and over 80% of the land is under direct human influence (Sanderson et al., 2002).

To relieve the human–environment tension and preserve ecosystems and related services, scholarship and policy have been devoted to curbing population size and altering production–consumption regimes. Recent research on the former thread (controlling population growth) dates back to Thomas Malthus’s Essay on the Principle of Population (Malthus, 1798), and has continued and risen sharply since the 1960s (e.g., Ehrlich, 1968; Meadows et al., 1972; Ehrlich and Ehrlich, 2006). Scholarship on the latter, i.e., altering production–consumption regimes, has been in play for many decades. A number of factors are found to play a role in relieving the human–environment pressures, including but not limited to agricultural intensification, technological advancement (e.g., energy acquisition), cultural/institutional adaptation, and market substitution (Boserup, 1965; Simon, 1990).

Scholarship has increasingly recognized the importance of coupled natural and human (CNH) systems. Since the 1990s top social and physical scientists have been calling for integration of social and physical processes in research and graduate training (Stern, 1993). During this time, we have witnessed a mushrooming of integrated human–environment graduate degree programs under various monikers. These often fall under the rubric of department or “school”, such as “Sustainability”, “Natural Resources”, “Environmental Studies”, and “Geography and the Environment”. These programs are fostering new cohorts of researchers prepared theoretically and methodologically to tackle research challenges related to coupled CNH systems. And challenges remain.

Until recently human–environment scholarship has been conducted largely in a paradigm characterized by unidirectional connections between natural and human systems, either “human systems constrained by or with input from/output to natural systems”, or “natural systems subject to human disturbance” (Liu et al., 2007; An, 2011). To better understand the multifaceted complexity in many human–environment systems, particularly feedback and dynamics, the last decades have witnessed the advent and increasing popularity of a new paradigm: the coupled natural and human systems approach. For instance, the National Science Foundation (NSF) has recently launched a CNH program that spends millions of dollars annually to fund innovative CNH system research. Similar terms for CNH systems include coupled human and natural systems (CHANS; Liu et al., 2007) and socio-ecological or socio-environmental systems (SES; e.g., Ostrom, 2007). Whatever name we use, this new paradigm treats human and natural systems in an integrative manner, emphasizing the multi-dimensions of complexity, including feedback, nonlinearity and thresholds, heterogeneity, and time lags in the associated coupled systems (Liu et al., 2007).

2. The special issue

The above coupled natural and human systems paradigm is undoubtedly an advancement in both theory and methodology towards better understanding of human–nature relationships and coping with the many related theoretical and practical issues. However, until the present, no synthetic and systematic work has been devoted to answering a crucially important question bridging human and natural systems: how are human decisions made and modeled in such coupled systems?

In an attempt to address this question, the first author organized a symposium titled “Mapping and Disentangling Human Decisions in Complex Human–Nature Systems” for the 2011 American Association for the Advancement of Science (AAAS) Annual Meeting in Washington, D.C. on February 18, 2011. Accordingly, with support from the editors of *Ecological Modelling*, we decided to present to the CNH research community a special issue on modeling human decisions. To widen the scope of papers, an open call under the same title was sent to multiple email lists or websites, including the list of Ecological Society of America (ECOLOG-L) and that of the Population–Environment Research Network Discussion List (PERN). The call received many enthusiastic responses, among which three papers, i.e., Gray et al. (2011), Tang and Bennett (2011), and Shang et al. (2011), were selected to complement the AAAS symposium papers.

Ten papers are included in this special issue. They vary in the following aspects of human decision making in complex CNH systems: (1) what human decisions are modeled (from the abstract figured world, perceptions, and mental models that precede decisions, to the very specific CNH-related decisions); (2) what predictors may explain such decisions or pre-decision precursors (from abstract affective ecologies to socio-demographic or economic factors to geographical variables); (3) what goals can be achieved (from philosophical exploration, to site-based problem solving, to technical

0304-3800/$ – see front matter
doi:10.1016/j.ecolmodel.2011.10.023

Table 1
Summary of selected papers.[a]

Paper by	Decisions (mentality)	Predictors	Goal	Model units	Spatial scale	Major methods
Aitken and An	Figured world	Affective ecologies	Understand environmental complexity	Individual or group of people, etc.	Nature reserve (China)	Qualitative analysis, critical thinking
An	Various decisions	Various variables	Overview of modeling human-decision	N/A	N/A	Review, synthesis
Chen et al.	Reenroll land in GTGP[b] program	Socio-demo-economic factors, land attributes	Understand effects of social norms	Households	Nature reserve (China)	Agent-based models, interview
Drewes and Silbernagel	Where to harvest (travel dist.)	Lake distribution, management regime, etc.	Shared regional conservation	Wild rice harvesters	Six lakes in USA	Government data, field survey, interview, spatial narratives
Gray et al.	Mental models about system components and connections	Groups each individual belongs to	Better policy through participatory knowledge integration	Individual Stakeholders	Summer flounder fishery in USA	Fuzzy-logic cognitive maps, graph theory
López-Carr et al.	Change or amount in woody vegetation	(Change of) Population density, production, consumption	Various influences on LULC	Municipalities and departments	Country (Guatemala)	Multi-level modeling, geographically weighted regression
Price et al.	Elicitation of experts' input	Groups the individual belongs to	Compare and visualize conservation strategies	Individual experts	One forest and one watershed in USA	One-to-one talk, (web) workshop, spatial narratives
Shang et al.	Prescribed four management alternatives	Seven chosen criteria	Evaluate management alternatives	Pixels	National forests in USA	Connecting different models, multi-criteria evaluation
Tang and Bennett	Search spatial neighborhood, and opinion exchange	Distance between agents, parameter thresholds	Higher computing performance	Virtual agents	No real sites (virtual space)	Agent-based modeling, parallel computing
Wandersee et al.	Perception of human impact on environment	Demographic, policy, livelihood, etc.	Understand environmental perception	Individual people	Nature reserve (China)	Interview, regression, GIS

[a] This table only aims to summarize the components related to understanding human decisions, and by no means intends to cover all major features of the selected papers.
[b] Grain-to-Green Program (GTGP) in China.

advancement); (4) what organizational units are employed (from individual people to large administrative units); (5) what spatial scales are used (from computer virtual space to country territory); and (6) what analysis or modeling approaches are used (from qualitative to quantitative, from bottom-up to top-down, etc. Table 1).

3. Towards modeling human decision making in complex natural and human systems

The above ten papers are not meant to exhaustively cover all aspects of modeling human decision making in coupled natural and human systems; subjectivity may arise when choosing papers. However, speculation on how these papers may be potentially linked could provide useful insight into how human decisions are made, understood, and modeled. Here we use a hypothetical scenario to demonstrate how these papers, as well as how the methods used in these papers, could be connected and complemented.

Assume that in a hypothetical human–nature system, various ecosystem processes (e.g., vegetation succession, disturbance) operate at the corresponding scales, and several endangered species are of primary interest to different groups of stakeholders. A local human population also depends on the system for different services it is providing, such as clean water, firewood, and gathering of several key plants. The system is subjected to increasing influences from regional and global processes, including ecotourism, migration, urbanization, and conservation. A generic challenge facing all stakeholders (local residents, government agencies, conservation groups, etc.) remains: how to better understand the complex relationships among the system components such that decisions can be made to secure a sustainable future that maximizes benefits for both humans and local ecosystems (including the endangered species). Suppose a researcher aims to integrate the perspectives and methods in this issue (thus the *integrator*) to address this crucially important challenge.

3.1. *Understanding the system*

From the perspectives of Aitken and An (2011), the integrator first seeks local people's understanding (could be emotional and subjective) towards the hypothetical human–nature system and its complexity. Such understanding focuses on the way the system components (assemblages) are reciprocally related and comprised of complex and ever-changing networks (*redes*). Such understanding, or figured world, centers around a sense of autonomy that determines not only local people's emotional well-being and security, but also their interaction with outside influences (e.g., state conservation policy, ecotourism). Furthermore, the integrator continues to dialogue with stakeholders who belong to different groups. Using the fuzzy-logic cognitive maps approach (FCM; Gray et al., 2011), critical components of the system (as perceived by stakeholders) and their interrelationships could be obtained and mapped.

3.2. *Relationship building*

If one component or assemblage (Aitken and An, 2011) in the system is of particular concern, then efforts may be devoted to various confirmatory (usually with theory or *a priori* hypotheses) or exploratory ("let-data-speak-for-it") analyses. Specifically, the integrator may quantify this component and collect related data. Using statistical analysis, it is possible to determine empirically quantitative relationships or test hypotheses between this component (dependent variable) and other components (independent variables, largely like transmitter or ordinary variables in the corresponding fuzzy-logic cognitive maps; Gray et al., 2011).

Excellent examples of this genre are Wandersee et al. (2011)'s exploration on local people's perception of human impact on environment, López-Carr et al. (2011)'s models on land use and cover change, and Drewes and Silbernagel (2011)'s analysis on wild rice harvesters' decision. Their work is characterized by a wide range of data (such as government data, field survey or interview data, satellite imagery, and GIS data), statistical (such as multi-level modeling, geographically weighted regression techniques, and logistic modeling) and geospatial techniques (such as GIS and spatial statistics), and a combination of qualitative and quantitative analyses (such as spatial narratives).

3.3. Scale

The success of a CNH researcher's work is both constrained and enabled by scale. Appropriate integration of space and place has long been eluded in coupled natural and human systems research efforts. Frequently, a methodological divide exists between qualitative research that highlights the local, place-based effects and quantitative research that examines spatial lag as a continuous or semi-continuous variable. The integrator decides to integrate local, place-based effects and spatially continuous information as shown in López-Carr et al. (2011). In their empirical analysis of population and land use/cover change in Guatemala, the authors show that nested influences can be successfully reconciled with spatial analysis by applying to the same data hierarchical and spatial regression models.

3.4. Systems modeling

Given the above information and knowledge about the system, the integrator wants to synthesize and integrate data and models from all the above steps, scale up decision-making processes from local to regional scale, mobilize the system over time, and simulate emergent systems dynamics. Systems modeling is an ideal tool for these purposes, and agent-based modeling can be particularly powerful (Parker et al., 2003; An et al., 2005). The above figured world, as well as fuzzy-logic cognitive maps, may precede the construction of an agent-based model because insights into the key system components and their relationships are the basis for model conceptualization, parameterization, calibration, and testing. The integrator decides to build a spatially explicit agent-based model to coalesce data and models and simulate the dynamics of the CNH system of concern. Chen et al. (2011)'s agent-based model follows such a pursuit through simulation of how reenrollment of a state conservation program in a Chinese nature reserve may be affected by social norms under certain socioeconomic, demographic, geographic, environmental, and policy conditions.

When modeling human decisions (a recognized strength of agent-based models), the integrator may find that a comprehensive overview of various decision models used in agent based simulations of CNH dynamics (especially their strengths and weaknesses) can be helpful. An's review paper (2011) makes an attempt to provide this assistance, summarizing nine categories of human decision models that are often used in agent-based modeling of CNH systems.

Empirical agent-based models, especially those related to coupled human–nature systems, often involve a large number of agents, pixels (or cells), and interactions, requiring considerable computing support. These models are thus highly computationally intensive (Wang et al., 2006; Tang and Wang, 2009), which may significantly slow down simulations. The integrator then uses parallel computing technologies and resources to speed up simulation. Tang and Bennett (2011), for example, demonstrate how high-performance and parallel computing technique may render multiple model runs and agent-based interactions being carried out concurrently and thus more efficiently.

3.5. Envisioning decision outcomes

With knowledge and models about the system obtained from the preceding (or other) steps, the integrator is charged with evaluating several management strategies, envisioning their potential future outcomes, and providing policy recommendations. Due to unavailability, limitation, or inadequacy of supporting information, information can be elicited from experts "whose knowledge base is not typically found in publications" (Price et al., 2011). Techniques such as one-on-one conversations, workshops, web-based workshops, and spatial narratives (storylines) can be used to obtain such information.

On the other hand, if landscape (or ecosystem) simulation models are available (e.g., the above agent-based model), management strategies may be used as input for such models. The simulation outcomes (e.g., in terms of species composition, age structure) may then be used as input to evaluate habitat suitability, economic returns, and whatever indices of interest; management decisions (or recommendations) can then be made through a multi-criteria evaluation. This approach is illustrated in detail in Shang et al. (2011).

4. Conclusion and future direction

Modeling human decision-making in complex natural and human
systems remains a combination of science and art; it is by no means an easy task. From the papers in this special issue (see Table 1 for summary), we can see that this task is by nature interdisciplinary, cuts across multiple spatial or temporal scales, makes use of both bottom up (e.g., agent-based models) and top down (e.g., GIS models) approaches, and synergistically incorporates qualitative and quantitative analyses. It is expected that more theoretical and empirical efforts should be invested in order to eloquently further this task.

In many instances, we aim to understand how decisions are made through observing the emergent outcomes (e.g., land use or cover) they generate and relating such outcomes to known data or information, usually for which some theory or presumption is applied (Lambdin and Geist, 2003). Such theory or presumption may be just what we want to detect or confirm. This circularity is not an inherent problem specific to our task of modeling human decisions in CNH systems. However, attention should be paid to the equifinality (alternative ways of attaining the same outcome) and multifinality (attaining alternative outcomes from the same inputs) nature of complex systems, including most CNH systems. This nature does not preclude our use of a top-down approach, but should caution us when building models or interpreting results to ask whether there exists a strong theoretical foundation.

As mentioned in An (2011), substantial efforts should be invested in seeking process-based decision-making mechanisms or models. In many instances, process-based models capture "the triggers, options, and temporal and spatial aspects of an actor's reaction in a [relatively] direct, transparent, and realistic way" (Barthel et al., 2008). Advances in related disciplines such as psychology, economics, and sociology will shed more light upon realistic reasoning processes, e.g., the role of beliefs, perceptions, and preferences on human decision processes (Ligtenberg et al., 2004). Furthermore, we advocate wider adoption of mixed methods, both qualitative and quantitative, as well as integrating spatially explicit with nested modeling approaches. Doing so will further our understanding of coupled natural and human systems in general, and specifically help address both structure and agency operating at different scales within human systems related to environmental change (Chowdhury and Turner, 2006). It is our hope that this special issue will contribute to developing more innovative approaches that facilitate better understanding and modeling human decisions in coupled natural and human systems.

References

Aitken, S.C., An, L., 2011. Figured worlds: environmental complexity and affective ecologies in Fanjingshan, China. Ecological Modelling.

An, L., Linderman, M., Qi, J., Shortridge, A., Liu, J., 2005. Exploring complexity in a human–environment system: an agent-based spatial model for multidisciplinary and multi-scale integration. Annals of Association of American Geographers 95, 54–79.

An, L., 2011. Modeling human decisions in coupled human and natural systems: review of agent-based models. Ecological Modelling.

Barthel, R., Janisch, S., Schwarz, N., Trifkovic, A., Nickel, D., Schulz, C., 2008. An integrated modelling framework for simulating regional-scale actor responses to global change in the water domain. Environmental Modelling & Software 23, 1095–1121.

Boserup, E., 1965. The Conditions of Agricultural Growth. Earthscan, London.

Chen, X., Lupi, F., An, L., Sheely, R., Viña, A., Liu, J., 2011. Modeling the effects of social norms on enrollment in payments for ecosystem services. Ecological Modelling.

Chowdhury, R., Turner I.I., B.L., 2006. Reconciling agency and structure in empirical analysis: smallholder land use in the Southern Yucatan, Mexico. Annals of the Association of American Geographers 96 (2), 302–322.

Drewes, A.D., Silbernagel, J., 2011. Uncovering the spatial dynamics of wild rice lakes, harvesters and management across Great Lakes landscapes for shared regional conservation. Ecological Modelling.

Dompka, V. (Ed.), 1996. Human Population, Biodiversity and Protected Areas: science and Policy Issues. American Association for the Advancement of Science, Washington, DC.

Ehrlich, P.R., 1968. The Population Bomb. Ballantine Books, New York.

Ehrlich, P., Ehrlich, A., 2006. Enough already. New Scientist 191 (2571), 46–50.

Gray, S., Chan, A., Clark, D., Jordan, R.C., 2011. Modeling the integration of stakeholder knowledge in social–ecological decision-making: benefits and limitations to knowledge diversity. Ecological Modelling.

Haberl, H., Wackernagel, M., Krausmanna, F., Erba, K.H., Monfred, C., 2004. Ecological footprints and human appropriation of net primary production: a comparison. Land Use Policy 21 (3), 279–288.

Lambdin, E., Geist, H.J., 2003. Dynamics of land us and land cover change in tropical regions. Annual Review of Environmental Resources 28, 205–241.

Ligtenberg, A., Wachowicz, M., Bregt, A.K., Beulens, A., Kettenis, D.L., 2004. A design and application of a multi-agent system for simulation of multi-actor spatial planning. Journal of Environmental Management 72, 43–55.

Liu, J., Dietz, T., Carpenter, S.R., Alberti, M., Folke, C., Moran, E., Pell, A.N., Deadman, P., Kratz, T., Lubchenco, J., Ostrom, E., Ouyang, Z., Provencher, W., Redman, C.L., Schneider, S.H., Taylor, W.W., 2007. Complexity of coupled human and natural systems. Science 317, 1513–1516.

López-Carr, D., Davis, J., Jankowska, M., Lopez-Carr, A.C., Clark, M., Grant, L., 2011. Space versus place in complex human–natural systems: spatial and multi-level models of tropical land use and cover change (LUCC) in Guatemala. Ecological Modelling.

Malthus, T.R., 1798. An Essay on the Principle of Population. University of Michigan Press, Ann Arbor [1959].

Meadows, D.H., Meadows, D.L., Randers, J., Behrens III, W.W., 1972. The Limits to Growth. Universe Books, New York.

Ostrom, E., 2007. A diagnostic approach for going beyond panaceas. Proceedings of the National Academy of Sciences of the United States of America 104, 15181–15187.

Parker, D.C., Manson, S.M., Janssen, M.A., Hoffmann, M.J., Deadman, P., 2003. Multi-agent systems for the simulation of land-use and land-cover change: a review. Annals of the Association of American Geographers 93, 314–337.

Price, J.M., Silbernagel, J., Miller, N., Swaty, R., White, M., Nixon, K., 2011. Eliciting expert knowledge to inform landscape modeling of conservation scenarios. Ecological Modelling.

Shang, Z., He, H.S., Xi, W., Shifley, S.R., Palik, B.J., 2011. Integrating LANDIS model and a multi-criteria decision-making approach to evaluate cumulative effects of forest management in the Missouri Ozarks, USA. Ecological Modelling.

Sanderson, E.W., Jaiteh, M., Levy, M.A., Redford, K.H., Wannebo, A.V., Woolmer, G., 2002. The human footprint and the last of the wild. BioScience 52 (10), 891–904.

Simon, J., 1990. Population Matters: People, Resources, Environment and Immigration. Transaction, New Brunswick, NJ.

Stern, P.C., 1993. A second environmental science: human–environment interactions. Science 260 (5116), 1897–1899.

Tang, W., Bennett, D.A., 2011. Parallel agent-based modeling of spatial opinion diffusion accelerated using graphics processing units. Ecological Modelling.

Tang, W., Wang, S., 2009. HPABM: a hierarchical parallel simulation framework for spatially-explicit agent-based models. Transactions in GIS 13 (3), 315–333.

U.S. Census Bureau, 2011. U.S. and World Population Clocks – POPClocks. Available from: http://www.census.gov/ipc/www/popclockworld.html.

Vitousek, P.M., 1994. Beyond global warming: ecology and global change. Ecology 75 (7), 1861–1876.

Vitousek, P.M., Mooney, H.A., Lubchenco, J., Melillo, J.M., 1997. Human domination of earth's ecosystems. Science 277, 494–499.

Wandersee, S.M., An, L., López-Carr, D., Yang, Y., 2011. Perception and decisions in modeling coupled human and natural systems: a case study from Fanjingshan National Nature Reserve, China. Ecological Modelling.

Wang, D., Berry, M.W., Carr, E.A., Gross, L.J., 2006. A parallel fish landscape model for ecosystem modeling. Simulation 82, 451–465.

Li An*
San Diego State University, Department of Geography, 5500 Campanile Drive, San Diego, CA 92182-4493, USA

David López-Carr
University of California, Santa Barbara, Department of Geography, 1832 Ellison Hall, Santa Barbara, CA 93106-4060, USA

* Corresponding author.
E-mail addresses: lan@mail.sdsu.edu (L. An), carr@geog.ucsb.edu (D. López-Carr)