NUS National University of Singapore | Department of Biological Sciences
Faculty of Science

SEMINAR

Tues, 30 Jun 2015 | 11am | Seminar Room 1 (S2 Level 4)

Hosted by Dr Roman Carrasco

Socio-ecological system models for supporting farm resilience: research needs, gaps and promising approaches

Quang Bao Le is a Senior Scientist on Agricultural Livelihood Systems for the CGIAR Research Program on Dryland Systems, starting in January 2015. He earned his engineer degree in Forestry from Hue University (Vietnam) and Mater degree in environmental science from Chiang Mai University (Thailand). He received a Ph.D in geography, ecology and natural resources management from the University of Bonn where he continued his postdoctoral research for the next three years. Dr. Le worked as senior researcher at Swiss Federal Institute of Technology (ETH) Zurich until 2014.

For years his research has focused on the development and application of human–environment system methodologies – ranging from frameworks to indicators and models (e.g., multi-agent system, cellular automata, system dynamics and bio-economic models) – with an aim to understand and support sustainable transitions of land use systems. He has conducted research into the analysis of adaptive land-use decisions of various types of human actors in coupling with ecological processes (e.g., soil/water redistribution, nutrient cycles, biomass productivity), and the feedbacks of long-term trends in land degradation or improvement into nature–society relationships regulating livelihood-landscape transitions. Dr. Le is serving on the editorial boards of three refereed journals. He taught regular and invited graduate courses on integrated land use system analysis and modeling, and has supervised the dissertations of several graduate students from Africa, Asia, Europe and Latin America.

By **Quang Bao Le**

CGIAR Research Program on Dyland Systems c/o International Center for Agricultural Research in Dry Areas (ICARDA)

It is important to increase the resilience of food production systems in the face of a changing climate, land scarcity, and changing demographics and market conditions. As farm resilience is a high-level system property emerged from social-ecological interactions, its direct measurement is difficult because it requires measuring the thresholds or boundaries that separate alternate stability regimes of the farm system. However, systems' modeling for supporting agricultural resilience is still in an early stage. Through critical review of state-of-the art literature, we highlighted the new requirements of agricultural system modeling as they apply to management for farm resilience, limitations of contemporary agricultural systems modeling approaches, and promising directions for future research on the field. We conceptualized criteria for evaluating models' suitability for farm resilience studies. Multi-agent systems (MAS) modeling has appeared as a promising approach for understanding farming resilience that results from rich interactions and feedback among adaptive decision-making and natural processes (e.g. energy, mineral nutrient and water flows). Using the above-mentioned criteria we also analyzed the current limitations of this model family and elaborate possible future developments as subjects of follow-up studies. I will show progresses of our on-going projects on agrarian landscape transitions using hybrid MAS modeling. At the end, I introduce a CGIAR working group on Integrated Systems Analysis and Modeling (iSAMG), in which our work embedded, to support building agricultural livelihood security in dryland at scale.

Keywords: farming system model, resilience, meta analysis, nutrient management, multi-agent system

Artwork by Ann Nee, DBS, NUS

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Food security and better livelihoods for rural dryland communities

Socio-ecological System Models for Supporting Farm Resilience: Research Needs, Gaps and Promising Approaches

Quang Bao Le
Agricultural Livelihood Systems
CRP Dryland Systems

Department of Biology, NUS, Singapore | 30 June2015

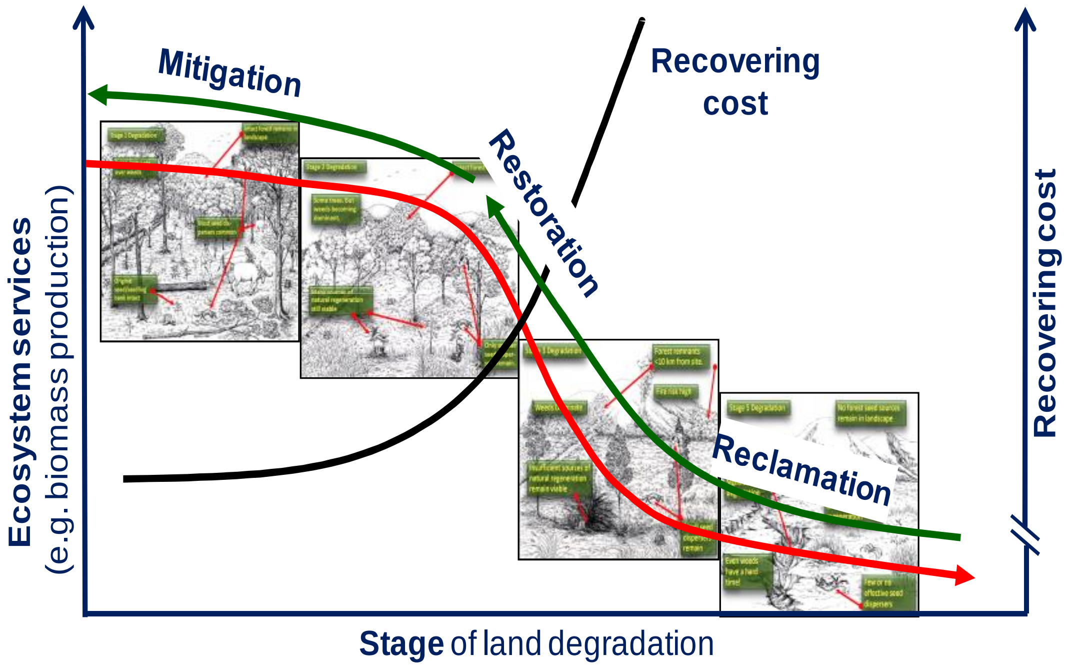
Main points

- Agricultural landscape resilience (ALR) and research challenges
- Criteria for an ideal model for ALR
- Review of contemporary modeling methods
- Multi-agent system (MAS) modeling for ALR: prospects, current limitations, on-going progresses
- CGIAR Research Program on Dryland Systems: integrated Systems Analysis and Modelling Group (iSAMG)

Agrarian landscape transitions

- Managing landscape transition towards sustainability requires understanding and anticipating landscape transitions vs. scenarios of drivers

- Landscape transition
  - System-level change across thresholds of stability domain
  - Not take place in a vacuum, but is generated from multi-scale adaptations

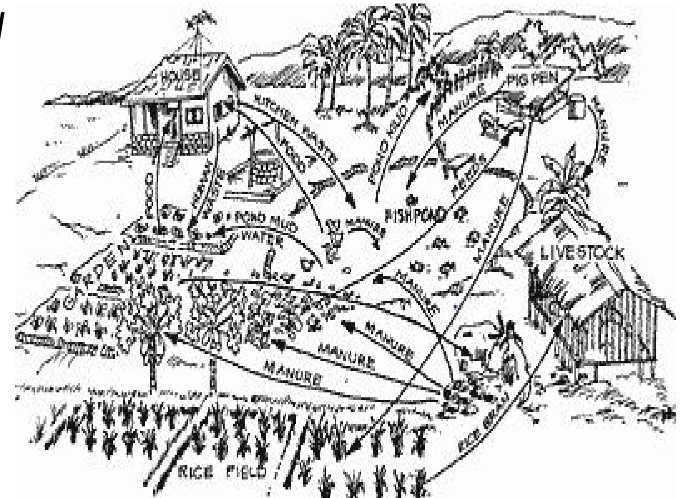


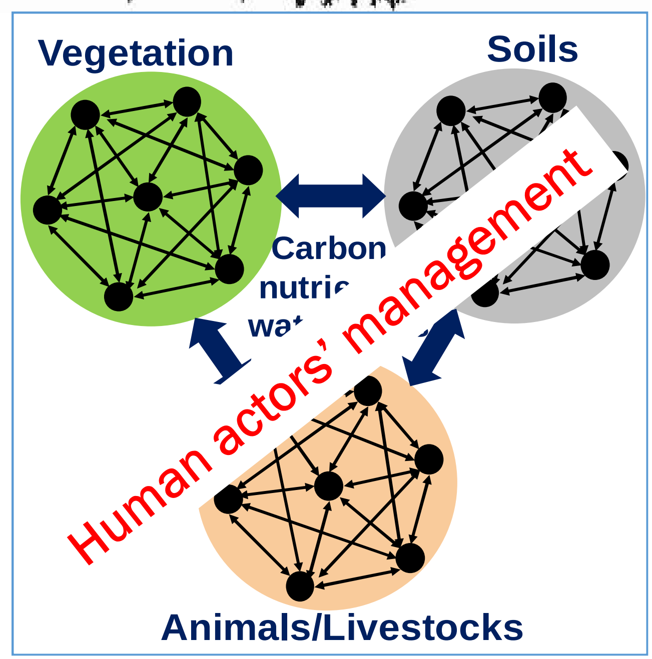
Source: Le (2012) 1st Global Soil Week; illustrative pictures from Elliott et al. (2008)

Understanding agrarian landscape transition: Human-environmental system perspective

Synthesis from Reynolds et al. (2007), Scholz (2011) and many others:

- Landscape sustainability involves the dynamics of coupled human-environmental system (HES)
- Crossing threshold of "slow/controlling" variables triggers shifts in system's stability domain
  - Environment: soil fertility, crop-soil-animal subsidiary linkages
  - Human: social, human, financial assets
- Feedback loops across nested hierarchies are crucial for system vulnerability or resilience
- Behavior of human actors is the key
  - Control (intentional/unintentional) feedback loops
  - Learning, co-operating to cope with contextual changes better
- Combined local and scientific knowledge base is key to manage desirable co-adaptation of HES.





Agrarian landscape resilience as desirable outcome

- Desirable persistence/buffering capacity: self-regulating capacity to assimilate perturbations without altering system's structure and function
- Adaptation: self-organizing capacity to accommodate shocks or stresses, thereby maintain system's stability regime.
- Transformability: capability to implement radical system innovations to transit to a new, better stability regime.
- Social equity: in both landscape services' benefit and restoration/protection responsibility

Problems and methodological requirements

Problem

- Complex human-environment interactions
- Uncertainties
- Externalities and trade-offs
  - vs. time
  - vs. space
  - vs. social group
  - vs. goal

Method requirement

- Interdisciplinary approach
- Uncertainty management
- Long-term perspective
- Micro-macro links
- Stakeholder participation
- Distributed outputs vs. space, time, and actor groups
- Multi-dimensional outputs

Problems and methodological requirements (continued)

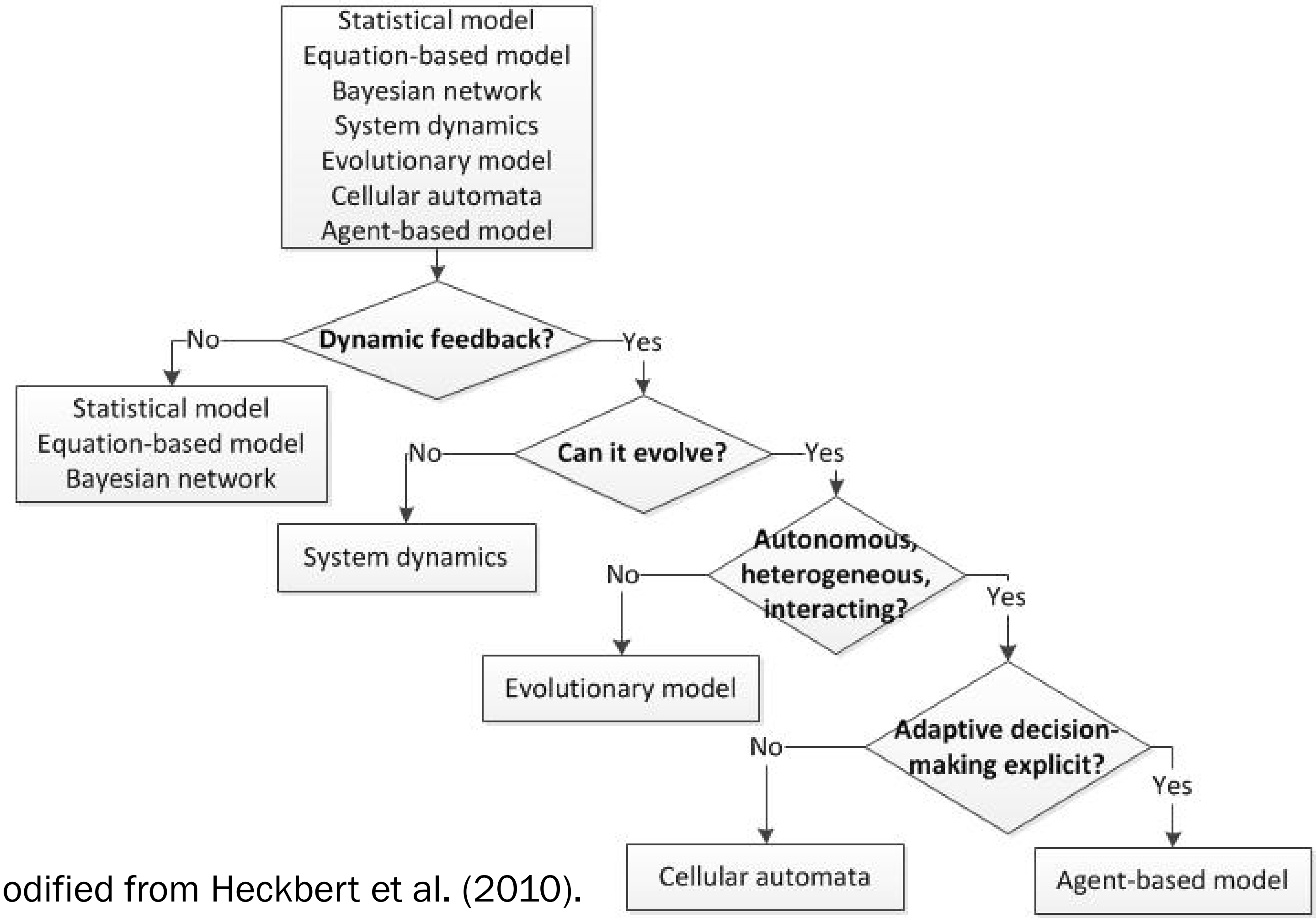
Problem	Method requirement
Flexible (not fixed) feedback loops genetated by actors‘ decisions	Actors' behavior explained
Actors‘ decisions changable along learning	Relevant learning process captured
Heterogeneity as important source of buffering, adaptive capacities	Within- and between- farm heterogeneities represented
Framing drivers	Sensitive to key drivers

Major types of integrated modelling considered

- Material flow analysis (MFA) models
- System dynamics (SD) models
- Bayesian belief network (BBN) models
- Bio-economic models
- Coupled component models
- Agent-based/multi-agent system model (ABM/MAS)

Detailed model definition with comparative senses can be found in Boulanger & Brechet (2005), Heckbert et al. (2010), Kelly et al. (2013)

Difference of some integrated models in the treatment of feedback, interaction and autonomy



Source: modified from Heckbert et al. (2010).

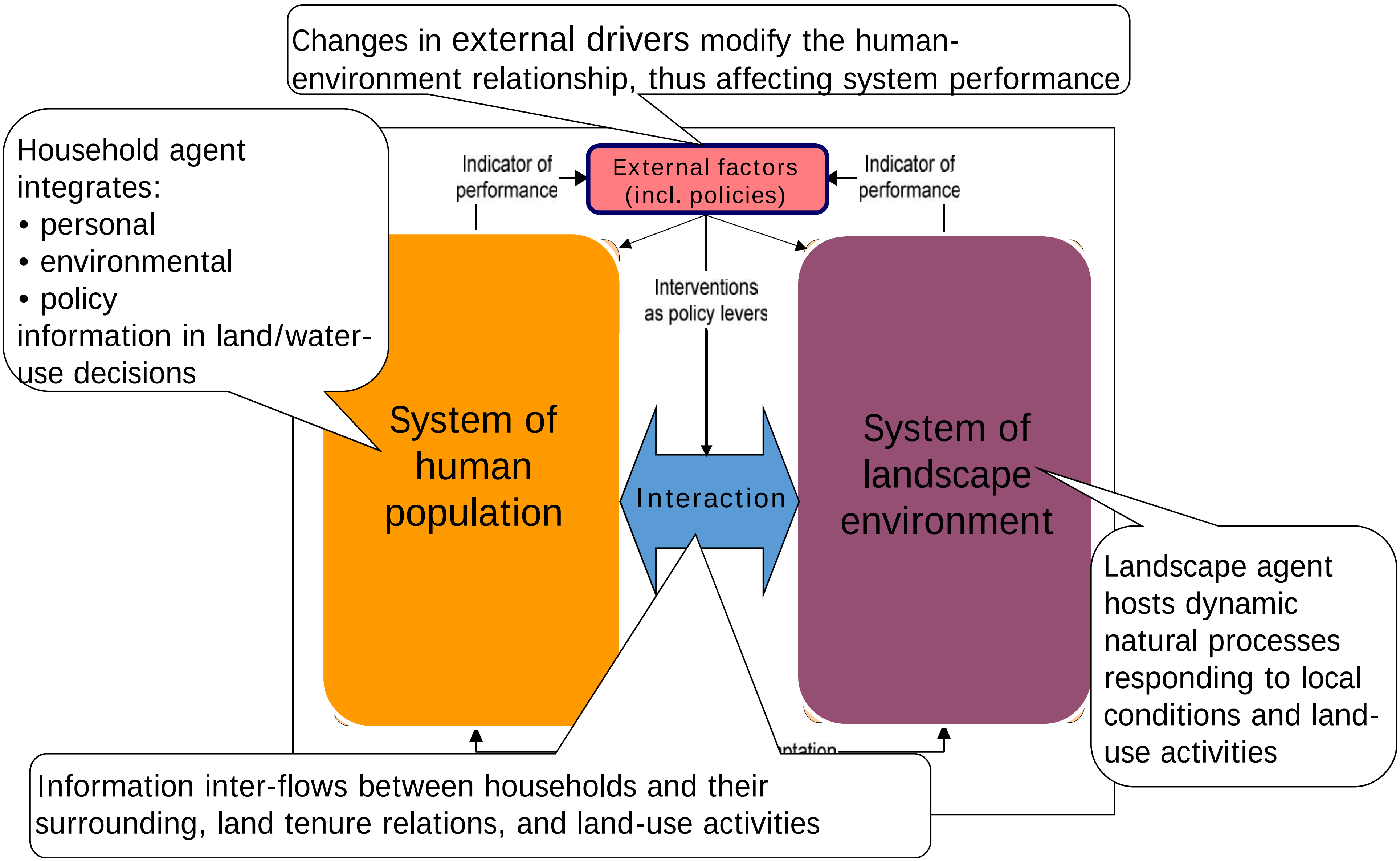
Table 1. Comparative assessment of contemporary farming system modeling approach with respect to criteria for farm resilient research. Note: publications in parentheses are as relevant examples).

Criteria (synthesized from Bousquet and Le Page (2004), Boulanger and Bréchet (2005), Kelly *et al.* (2013), Cabell and Oelofse (2012))	Output-input nutrient balance models (NUTMON[a] model (Den Bosch *et al.*, 1998a; Den Bosch *et al.*, 1998b))	System dynamics models (Shepherd and Sole, (1998); Sendzimir *et al.*(2011)	Bayesian Network models (Poppenborg and Koellner, 2013)	Bio-economic models (Witcover *et al.* (Witcover *et al.*, 2006))	Coupled component models (NUANCES[b] Giller *et al.*, (2011), IAT[c] (MacLeod *et al.*, 2007)), SEAMLESS (Van Ittersum et al., 2008)	Multi-agent system models (LUDAS[d] (Le *et al.*, 2008a; Le *et al.*, 2010b; Le *et al.*, 2012b), MP-MAS[e] (Schreinemachers and Berger, 2011))
Interdisciplinary	no[d]	strong	medium	weak [f]	weak [g]	strong
Long-term perspective	no	strong	no	weak	strong	strong
Uncertainty management	no	weak	strong	no	no/weak	medium
Local-global perspective	no	no	no	weak	strong	strong
Participation mediation	weak	strong	strong	weak	unclear	strong
Multi-scale feedback loops	no	no	no	no	unclear	strong
Actors' behavior	no	weak	strong	medium	no	strong
Social learning and adaptation	no	no - weak	no	no	no	strong [f]
Farm heterogeneity	strong	no	no	weak	strong	strong [g]
Multi-dimensional outputs	strong	strong	no	medium	strong	strong
Distributed outputs	no	no	no	no	no	strong
Driver sensitive - Biophysical - Economic - Social	 weak medium no	 weak unclear unclear	 weak medium strong	 weak strong no - weak	 strong med.-strong no	 weak - medium medium - strong strong

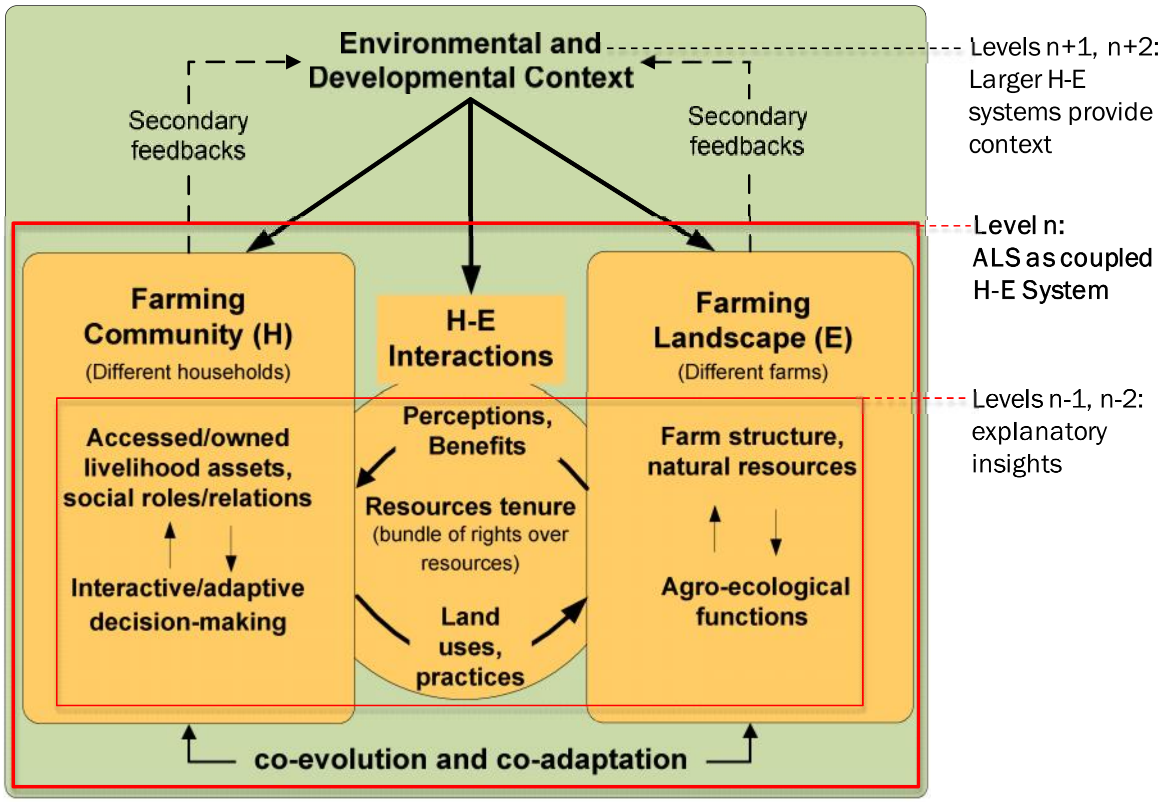
[a] NUTMON = NUTrient MONitoring
[b] NUANCES = Nutrient Use in Animal and Cropping systems – Efficiencies and Scales
[c] IAT = Integrated Analysis Tool
[d] LUDAS = Land Use DynAmics Simulator
[e] MP-MAS = Mathematic Programming - Multi-Agent System
[f] rather multi-disciplinary, e.g. disciplines stand side-by-side
[g] with some, rather all, MAS models, e.g. LUDAS model

Source: Le et al. (in-revision toward resubmission)

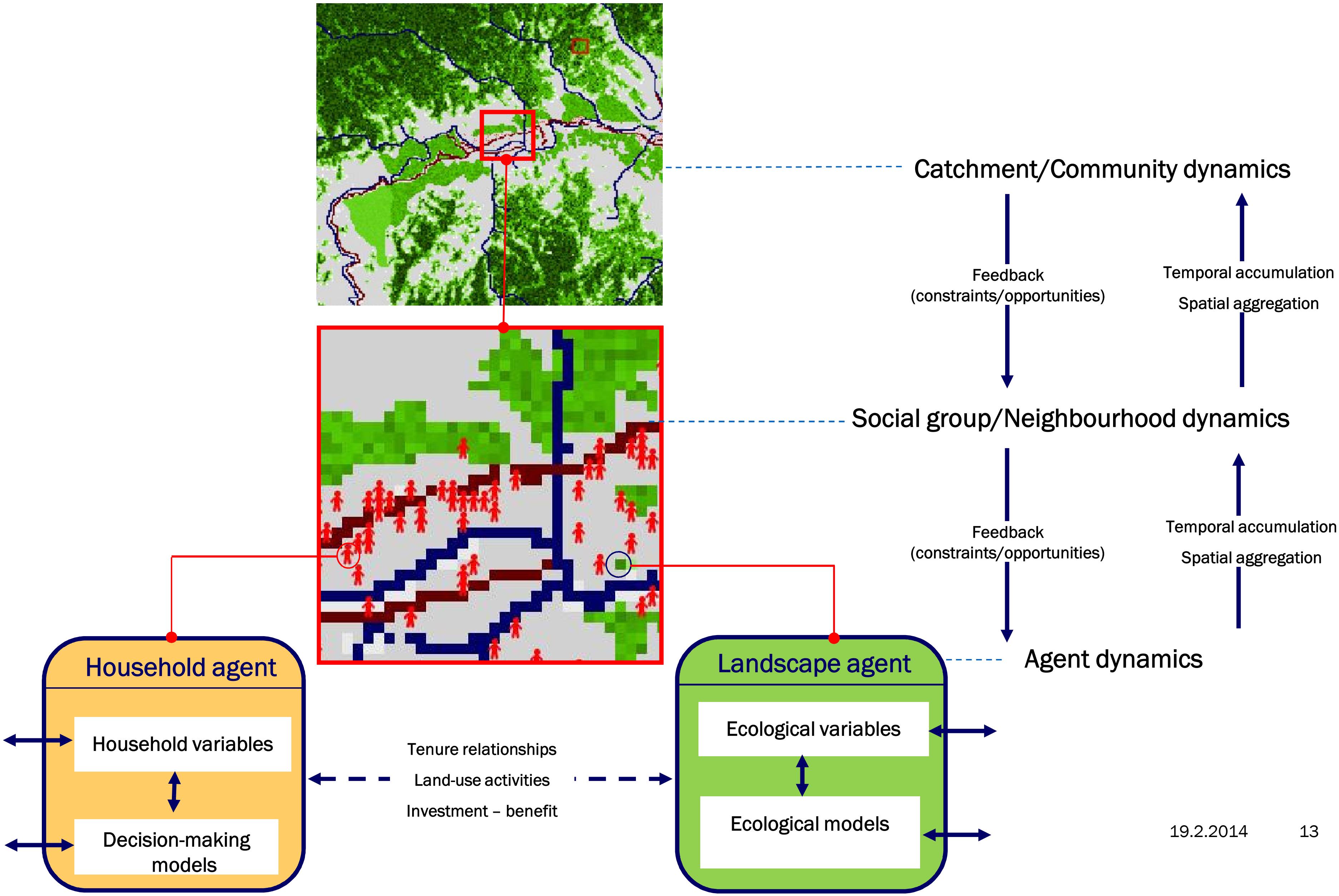
Land-Use Dynamic Simulator (LUDAS): A multi-agent system framework



LUDAS framework for modeling coupled agrarian landscape-community level



Cross-scale, generative feedback loops in LUDAS



An Operational Tool for Decision-Making in Sustainable Land/Water Management

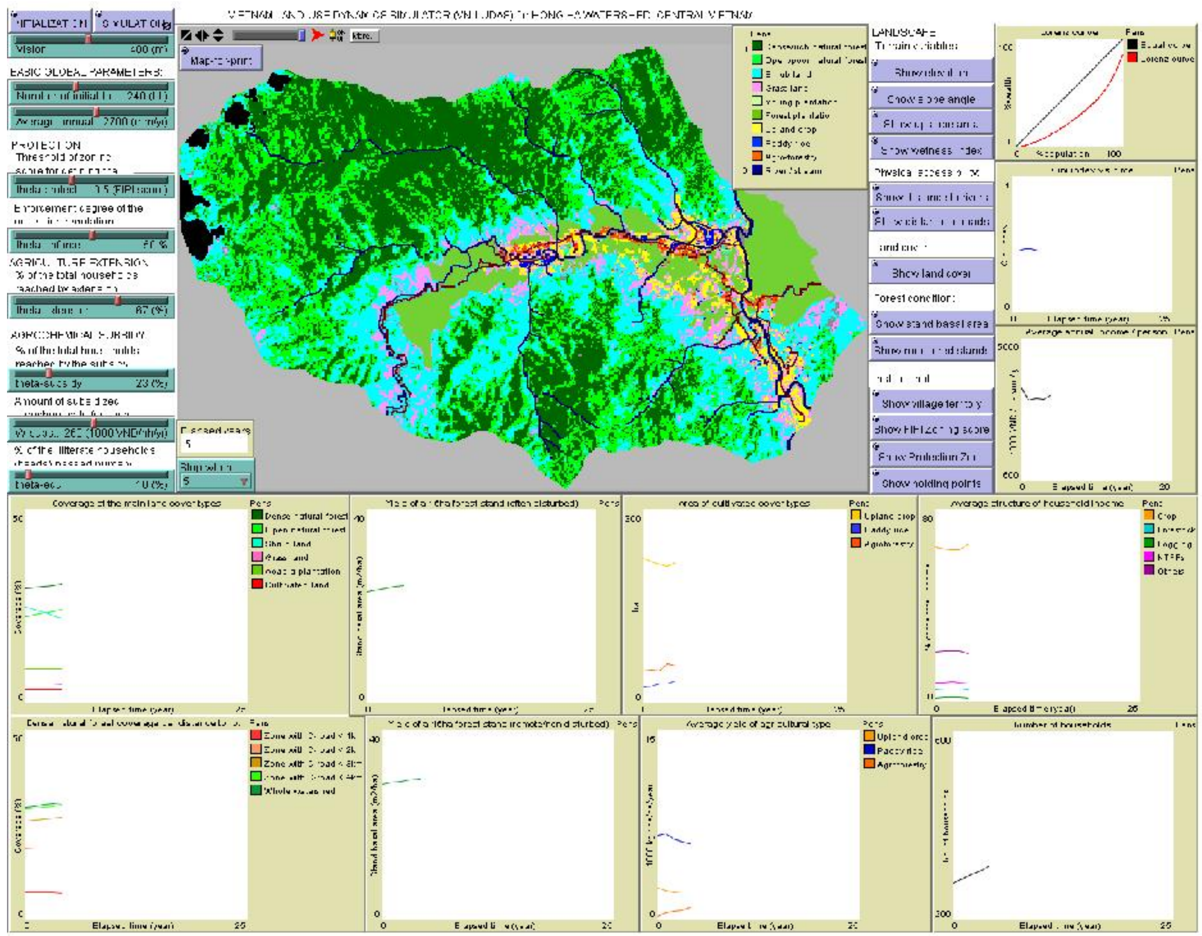
- User-friendly interface allows and stimulates stakeholder participation

  - Set policy/management options

  - Follow the future development of socio-ecological indicators on screen

- Simulation outputs (maps and graphs) are convertible to standard GIS and spreadsheet formats for other usages

  (see GUI of VN-LUDAS)



LUDAS's interface for Hong Ha catchment, central Vietnam

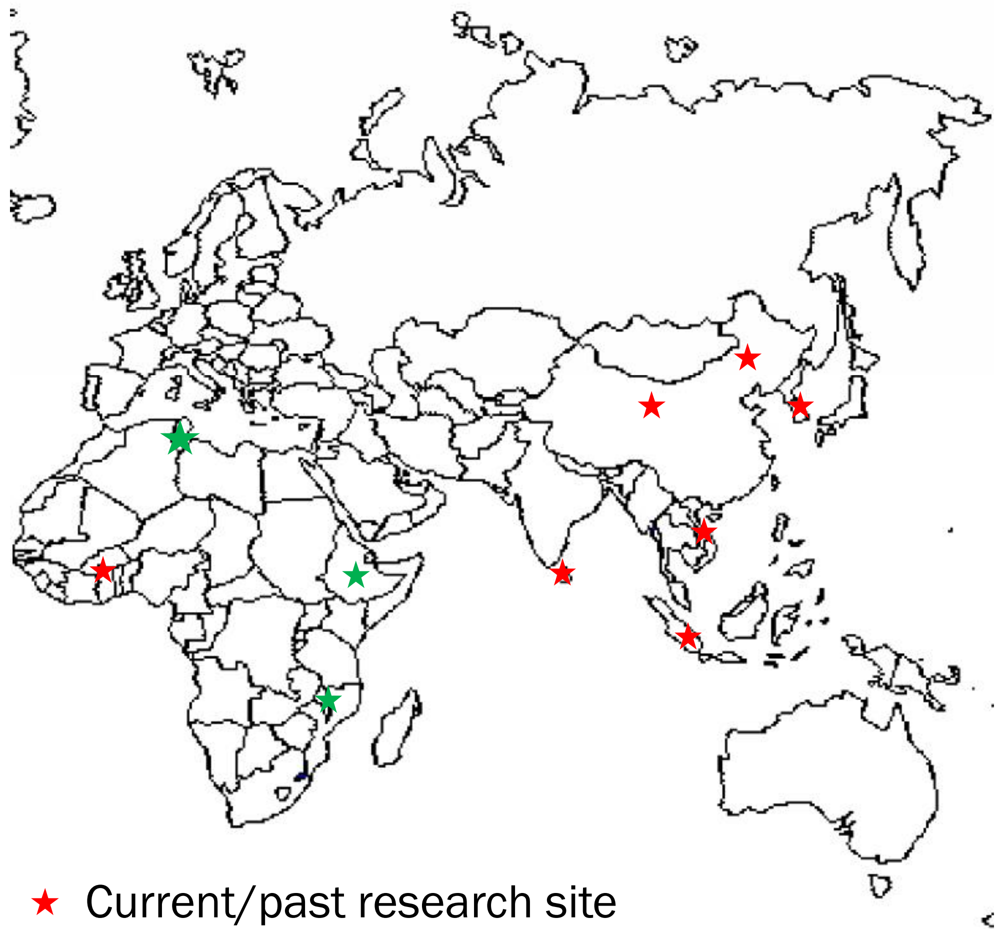
Context-based specifications and applications of the modeling framework

In different social-ecological regions:

- Tropical forests
- Semi-arid zones
- Coastal zones

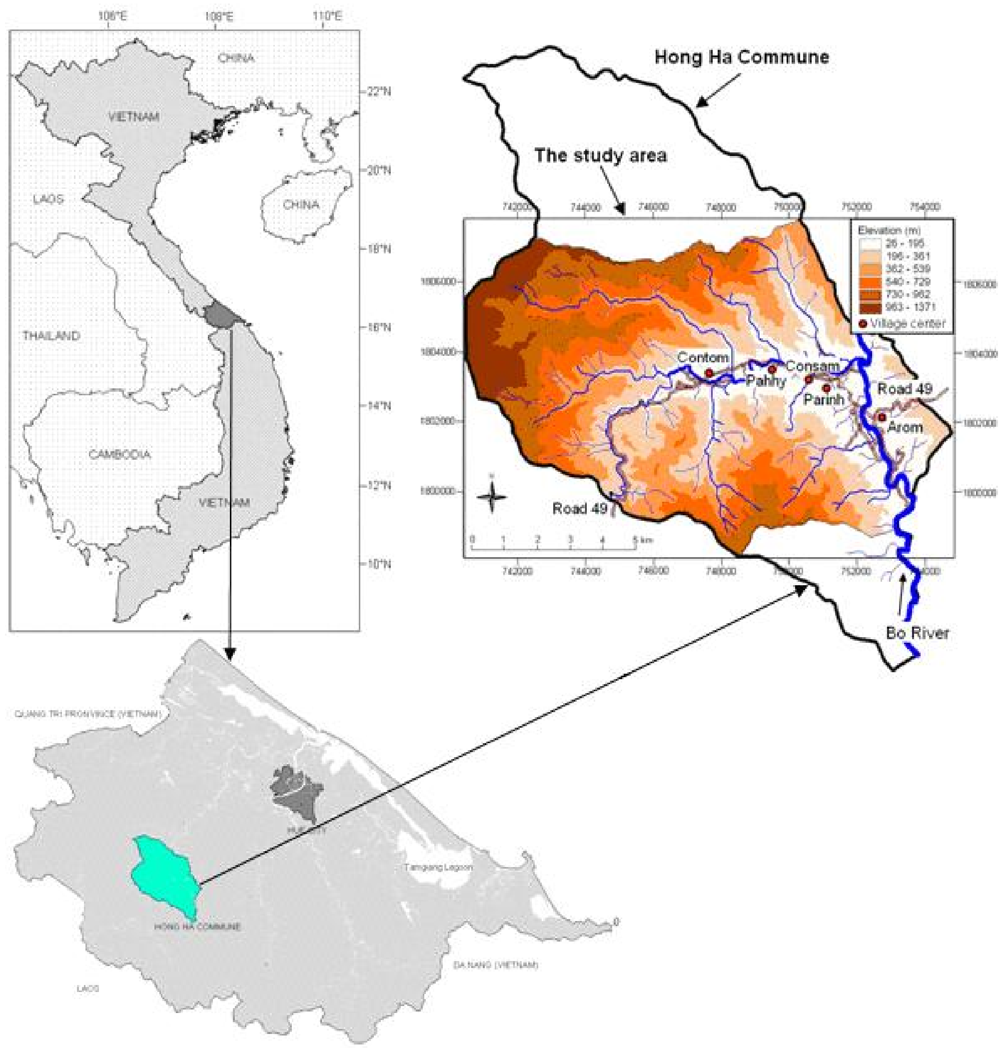
By different research teams:

- Universities (Bonn, ETH Zurich, Tokyo, etc.)
- CGIAR centers



Application of LUDAS for Hong Ha catchment (Vietnam)

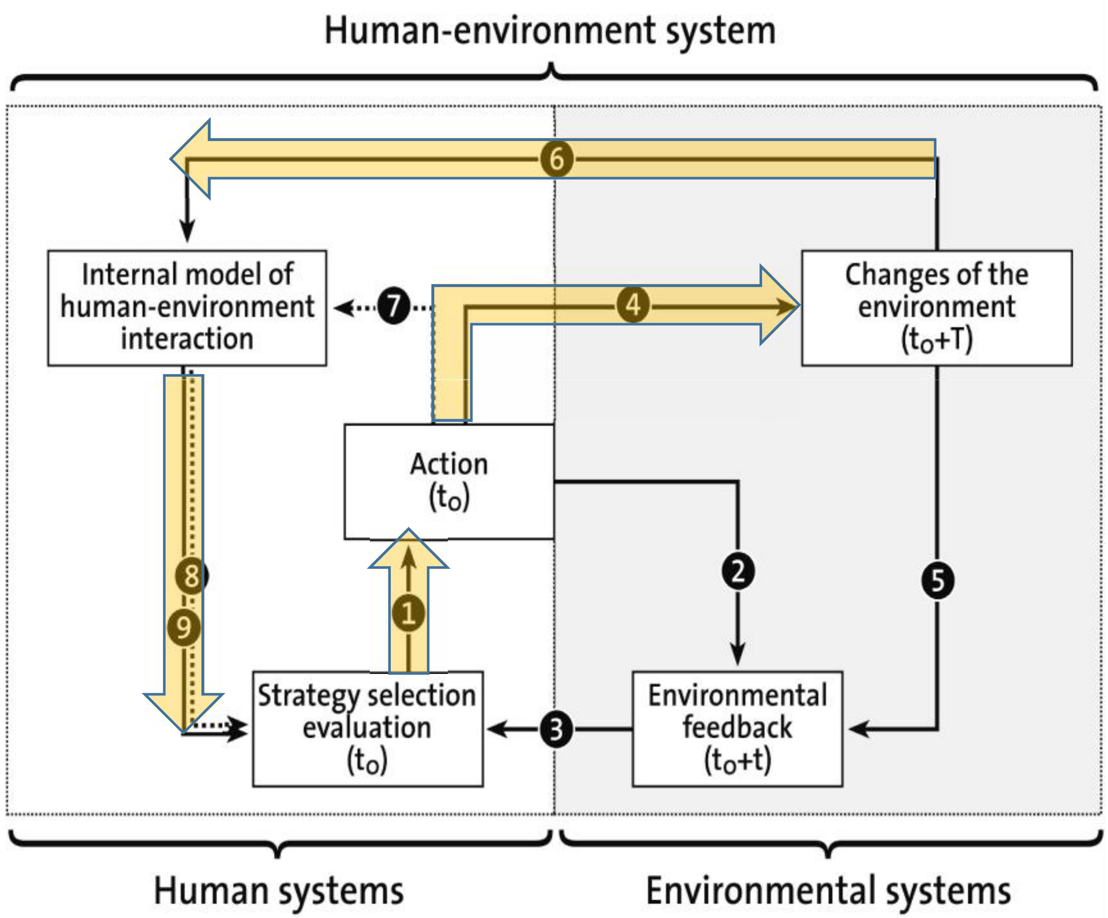
- Size of the study area: 100 km^2
- Protected mountain watershed in tropical forest zone
- 240 households who are agriculture- and forest- dependents
- Puzzles in policy decisions in:
  - Forest protection zoning
  - Agricultural extension
  - Agrochemical subsidy



Thua Thien – Hue province

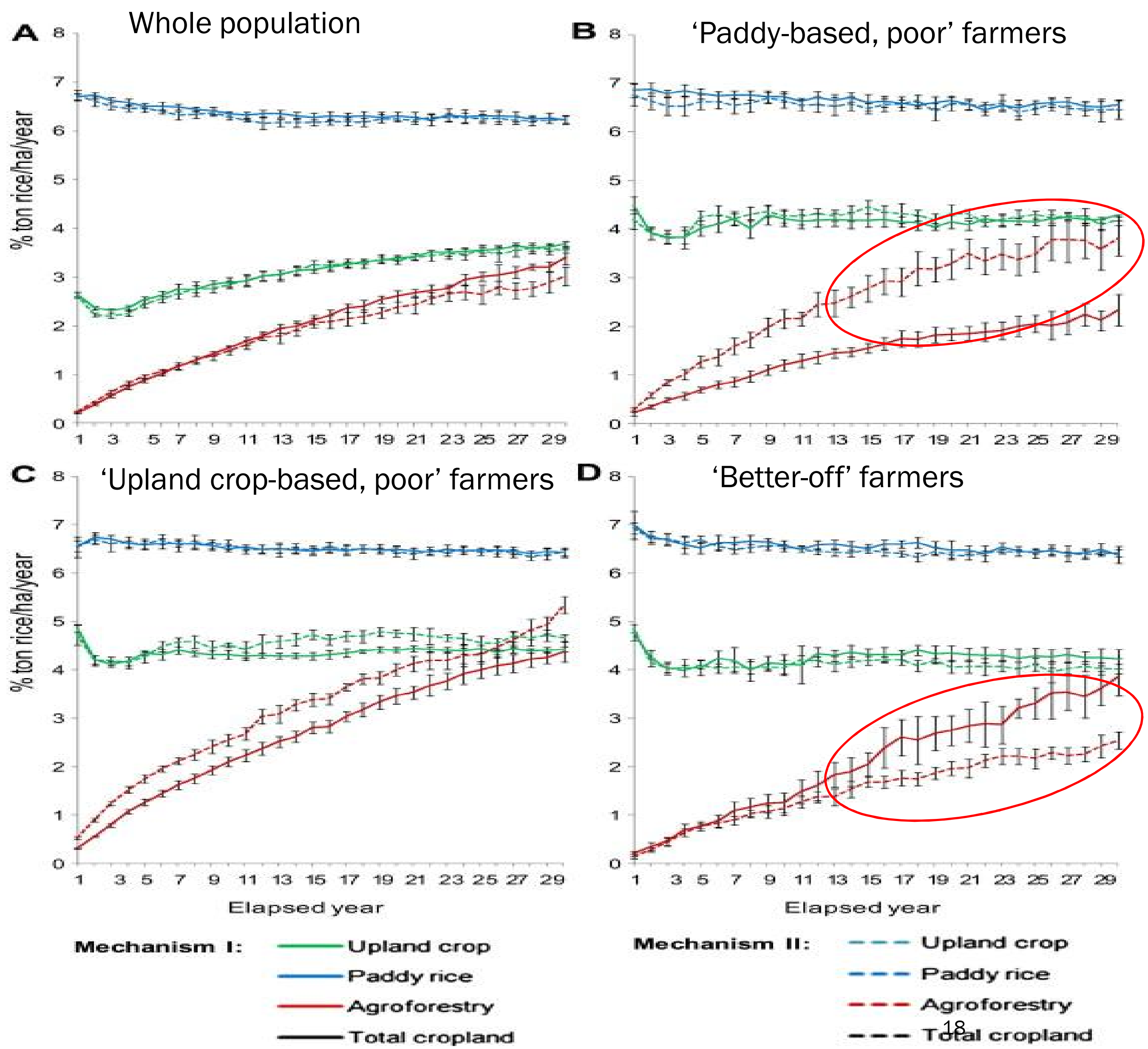
Test ex-ante impacts of farmers' adaptive learning

WHAT will be happen in the baseline dynamics IF adaptive learning is included (loops F1-2-3 and F1-4-6-8-9 considered) compared to the excluded case (only loop F1-2-3 considered)?



Source: Scholz (2011), Le et al. (2012)

The importance of adaptive learning



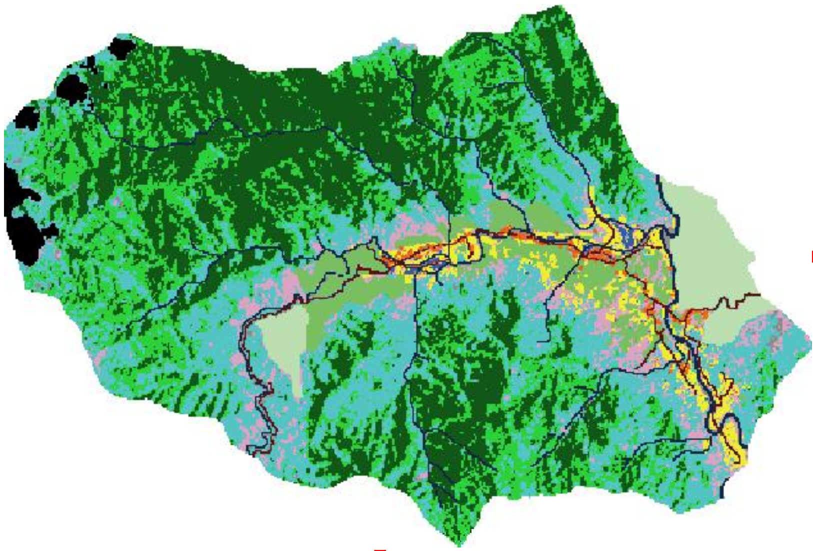
Le et al. (2012). *Environmental Modelling & Software* 27-28: 83-96

Pilot application of VN-LUDAS: Potential impacts of land-use policy changes on community-landscape dynamics

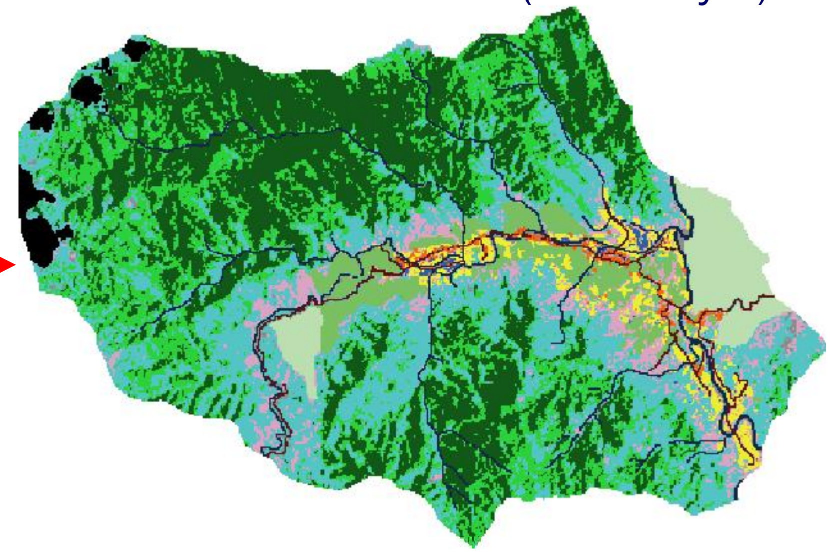
- Use-case 0: Base-line (current trend)
- *Use-case P*: what are potential integrated effects of changes in protection area zoning on forest resource and community income (incl. equity)?
- *Use-case S*: what are potential integrated effects of changes in agrochemical subsidy on forest resource and community income (incl. equity)?
- *Use-case E*: what are potential integrated effects of changes in agricultural extension reaches on forest resource and community income (incl. equity)?
- *Use-case I*: what are potential integrated effects of combining changes in three factors above on forest resource and community income (incl. equity)?

Likely environmental impacts of changes in protection zoning

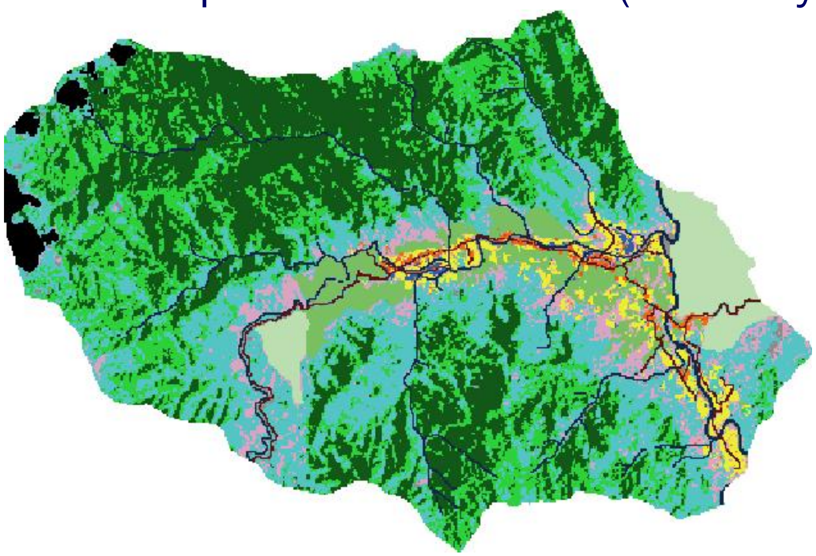
Initial status



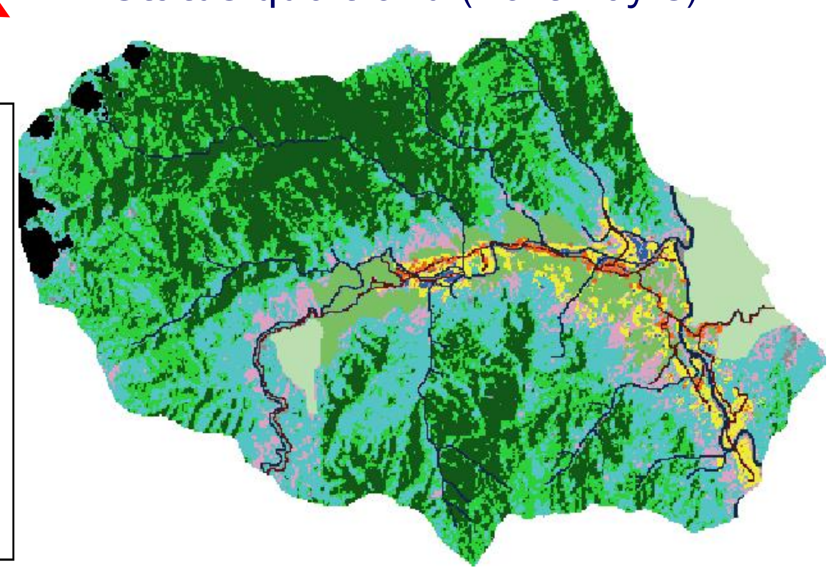
"No Protection" scenario (next 20 yrs)



"Strict protection" scenario (next 20 yrs)

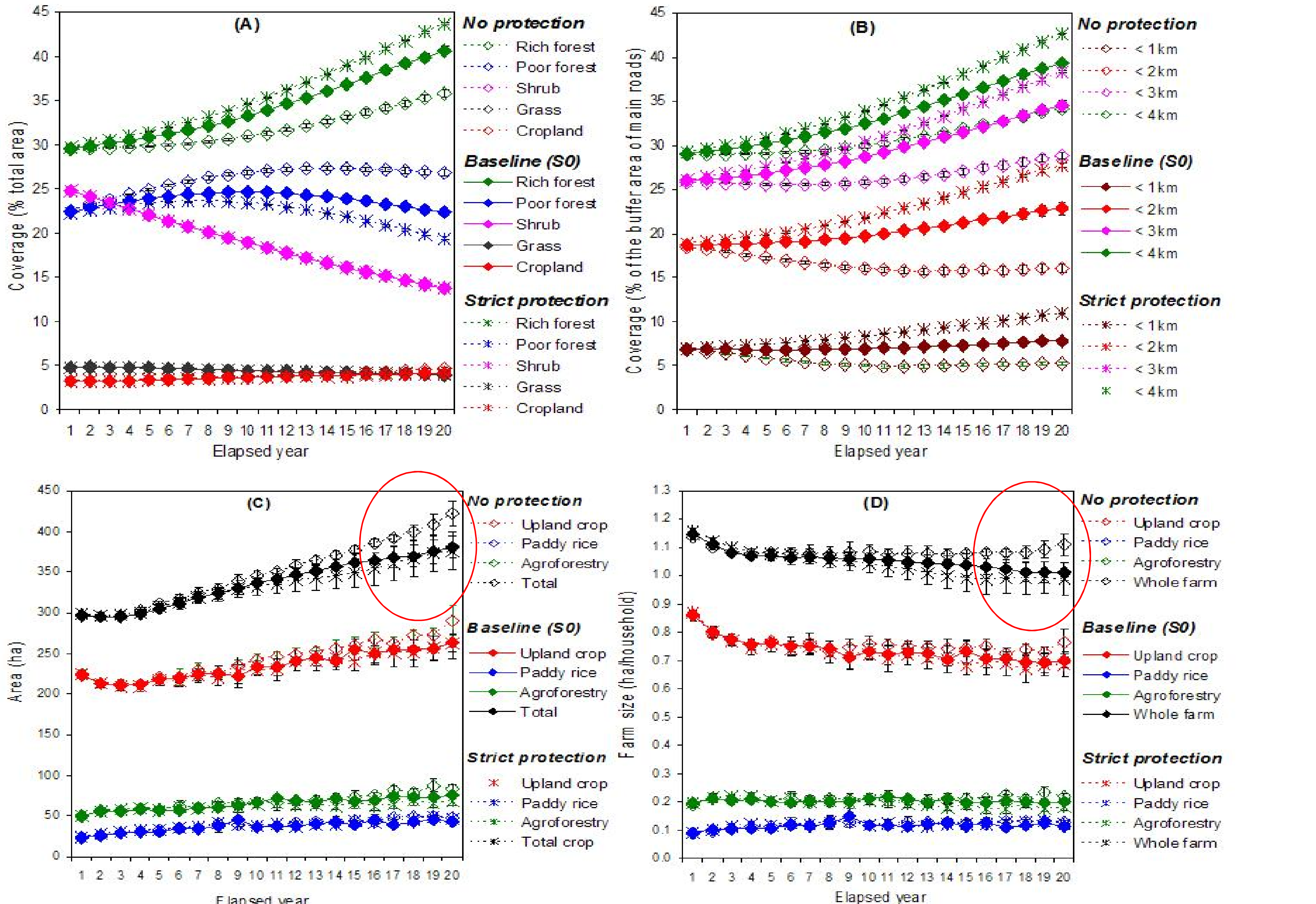


Status quo trend (next 20yrs)



Legend:
- Road
- River/stream
- Upland crop
- Paddy rice
- Agroforestry
- Shrub land
- Grass land
- Young plantation
- Forest plantation
- Open natural forest
- Dense natural forest
- Rocky surface
- No data

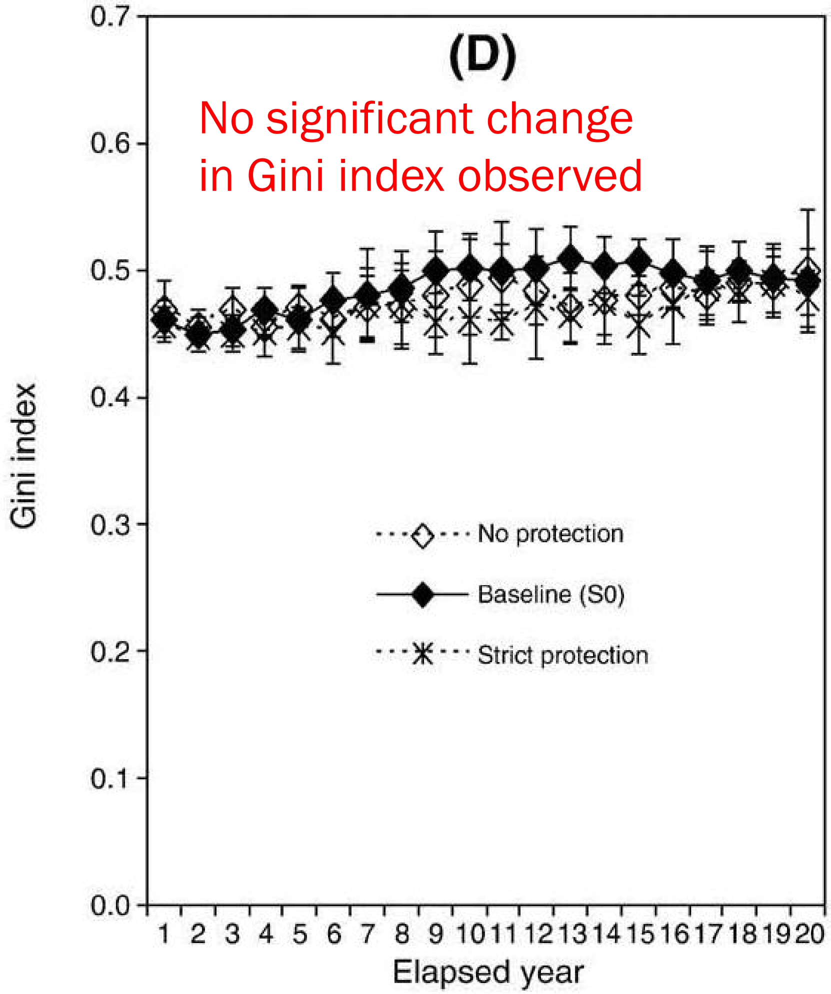
Delayed impacts of protection zoning on farm size

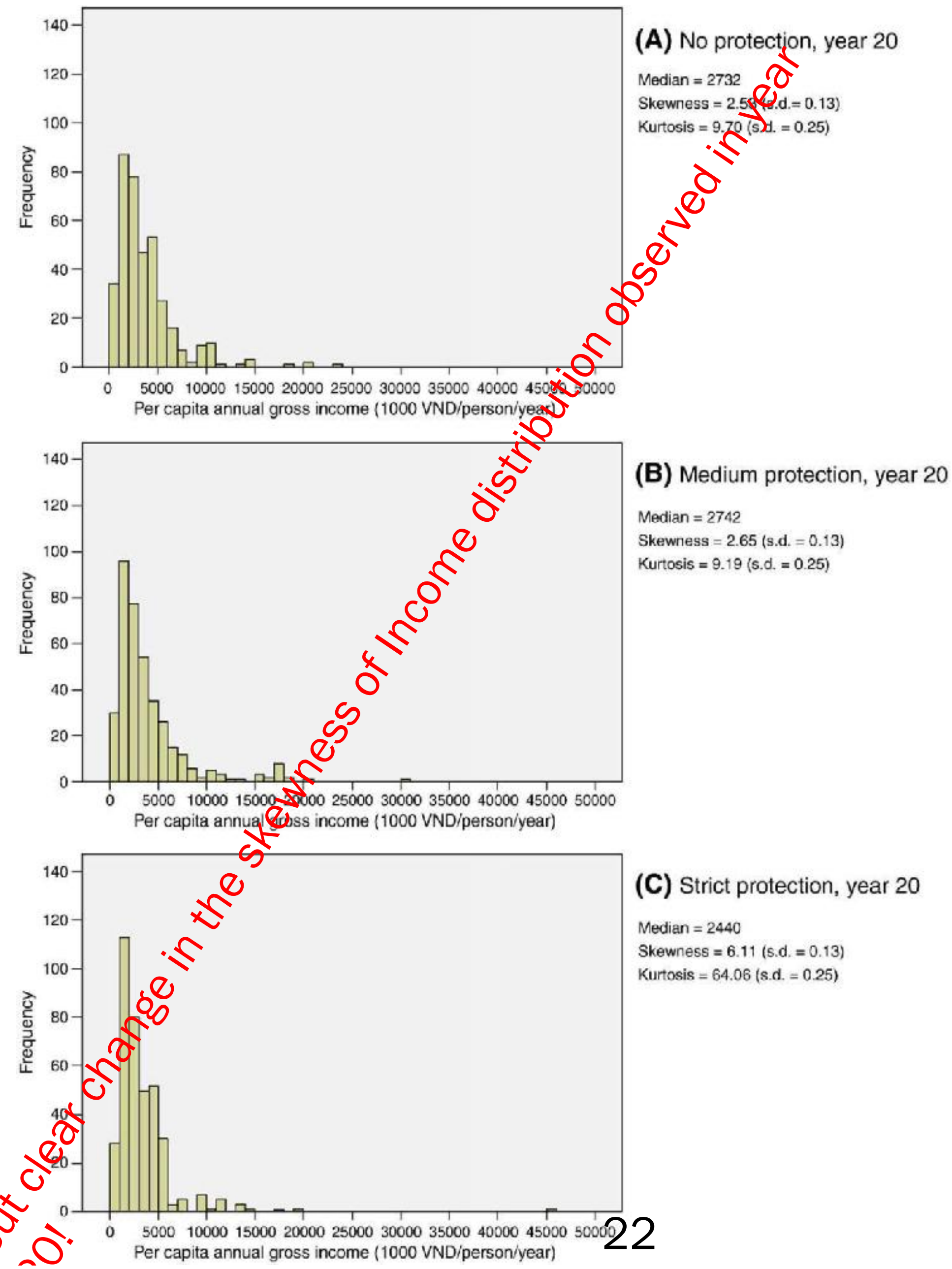


Source: Le at al. (2010) Ecological Informatics 5: 203-21

Delayed impact of protection zoning on income equity

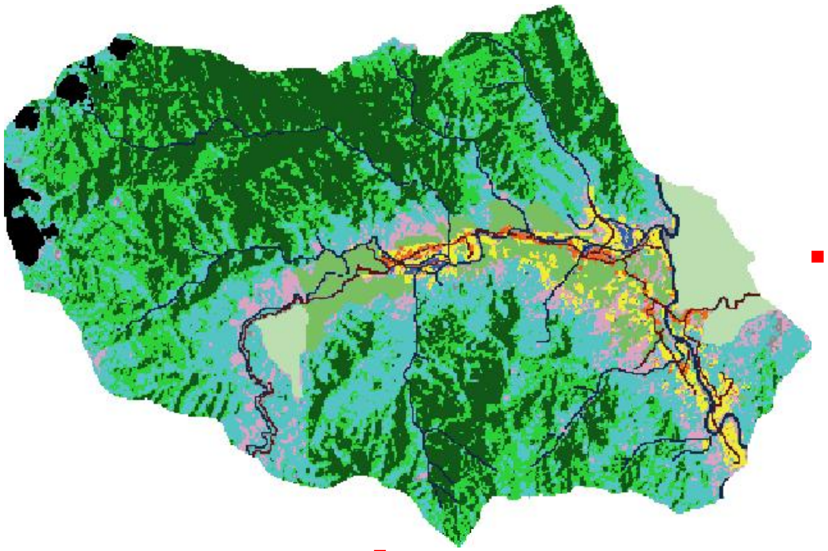
Source: Le et al. (2010)



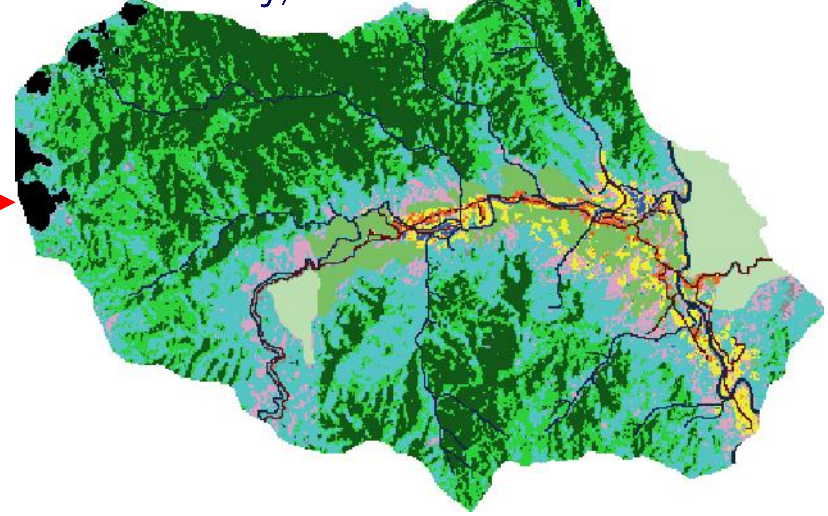


A sound combined policy intervention

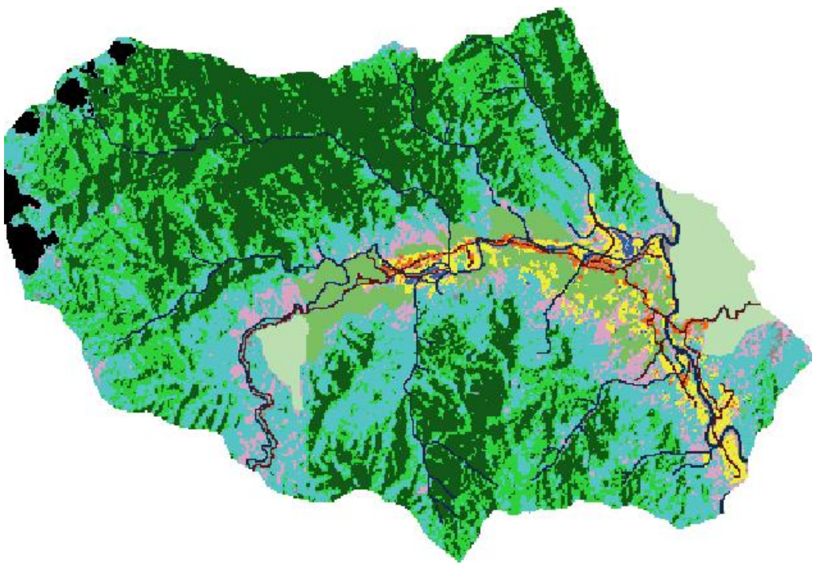
Initial status

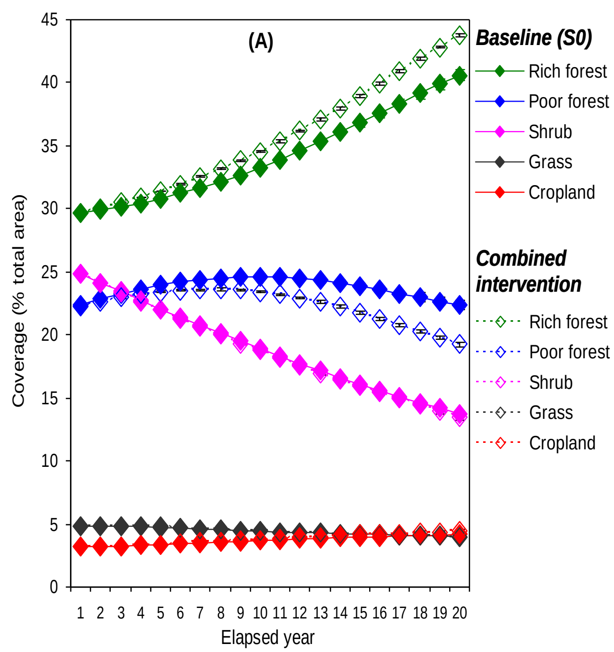


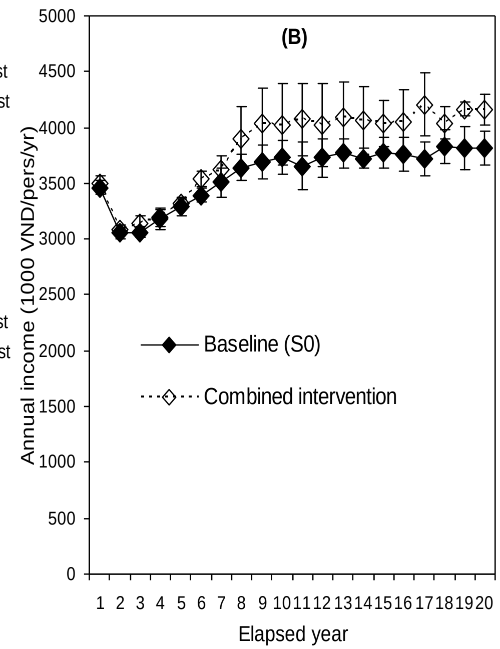
More law enforcement + arg. extension
+ minor fertilizer subsidy, BUT reduced protect area



Baseline (status quo) trend





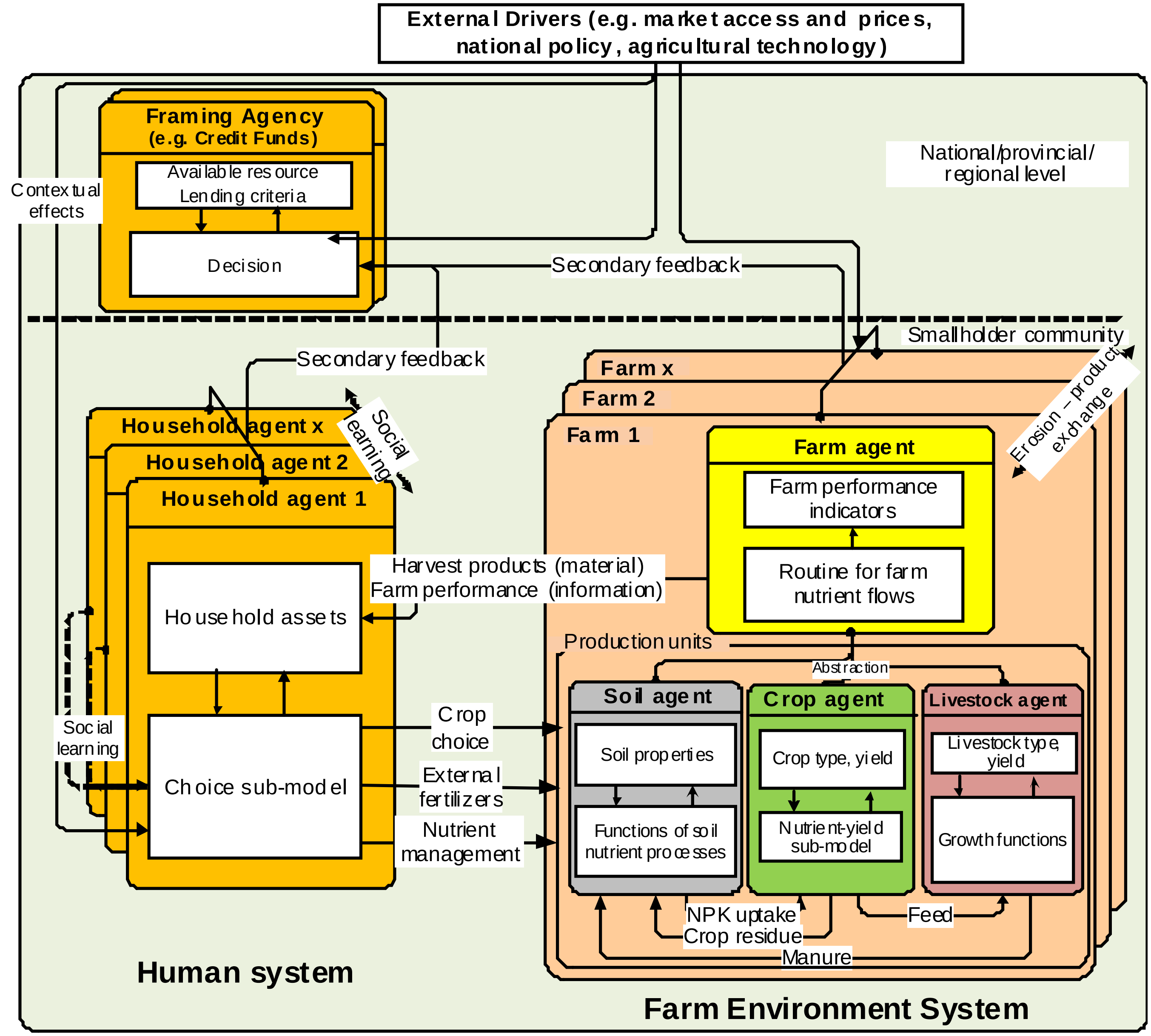


Limitations, but prospects as being studied

- Processes not yet incorporated
  - Nutrient flows and management
  - Farm heterogeneity
  - Important environmental externalities: GHG emission, water pollution, soil nutrient residual effects
- Resilience-relevant outputs
  - Onset of regime shifts
  - Buffering capacity indices
  - Adaptation indices
  - Transitions between farm types
- Systematic, rigorous model validation

New version capturing farm heterogeneities

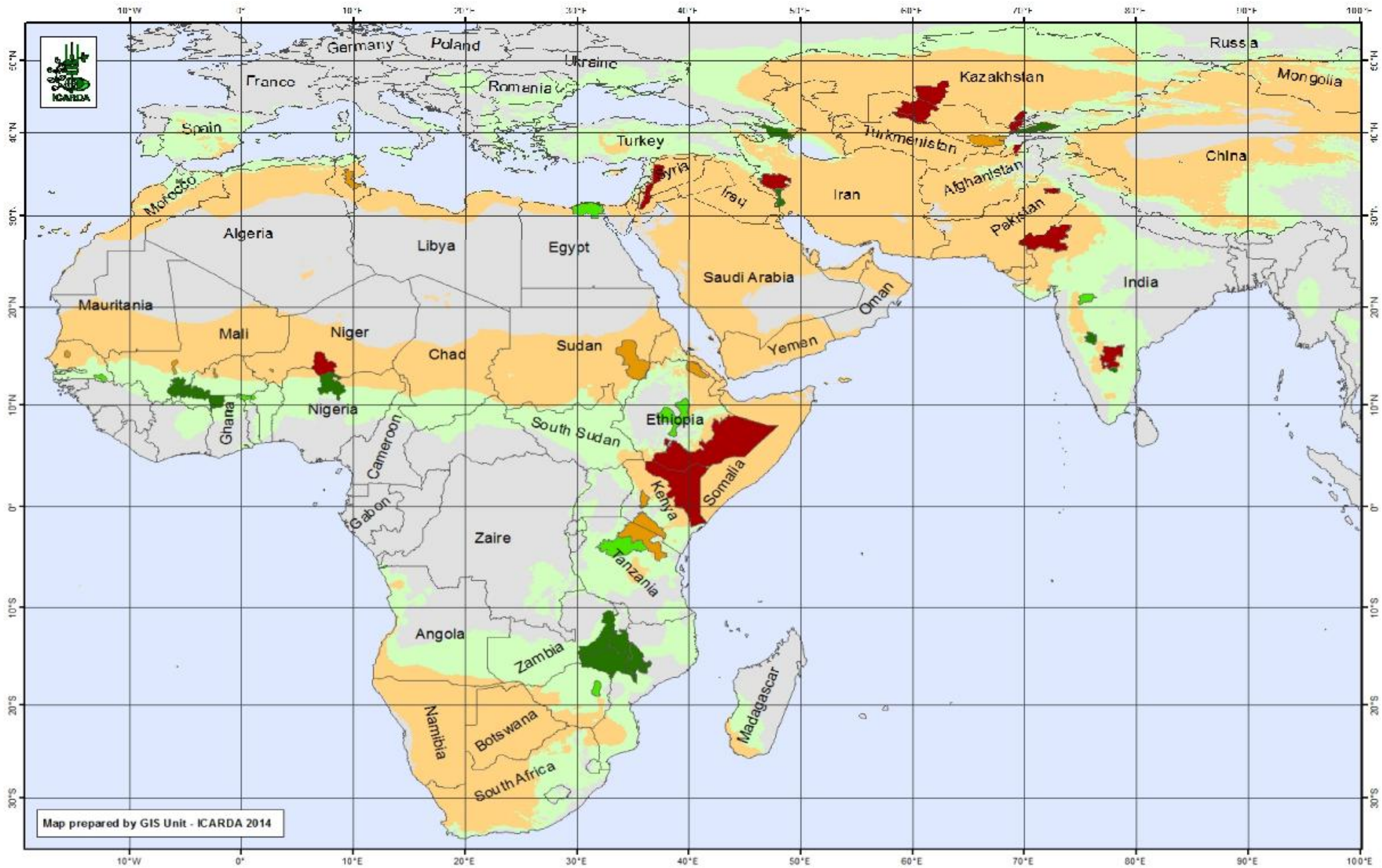
- Bio-physical Farm Agent represents farm heterogeneity
- Material flows, yield responses are shaped by farmers' decisions on crop uses, fertilizer uses, recycling, etc. → resilience arising from a rich structure of feedback loops that work in different ways (e.g. one kicking in if another one fails)
- Outputs like eco-efficiency, thresholds, tipping points are evaluated
- On-going case studies in Burkina Faso, Malawi



Source: Le et al. (2012)

Embedded in CGIAR Research Program in Dryland Systems (CRP-DS)

An integrated global research initiative (2012 – 2016) that develops resilient, diversified and more productive combinations of crop, livestock, rangeland and agroforestry systems that increase productivity, reduce hunger and malnutrition, improve the life of the rural poor and conserves the natural resources in drylands.



A community of practice in integrated Systems Analysis and Modeling Group (iSAMG)

- The iSAMG was set up by CRP-DS as a new initiative to improve systems research and link it to the impact pathway.
- The group includes system experts from CGIAR research centres and partners (Leeds University, UMR-Monpellier, Wageningen University).
- It provides platform for exchanging complementary integrated system modelling approaches, methods, tools and indicators.
- It encourages exchanges in experiences on how integrated system analysis and modelling can help improve impacts of research projects on the sustainable development of major agricultural livelihood systems.

RESEARCH PROGRAM ON Dryland Systems

Food security and better livelihoods for rural dryland communities

Thank you, any questions?

A global partnership to realize the potential of rural dryland communities

Led by: ICARDA — Science for Better Livelihoods in Dry Areas

In partnership with: ICRISAT — Science with a human face; Bioversity International; CIAT; Centro Internacional de la Papa — CIP; World Agroforestry Centre; ILRI — International Livestock Research Institute; IWMI — International Water Management Institute