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Dryland Systems

Food security and better livelihoods for rural dryland communities

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

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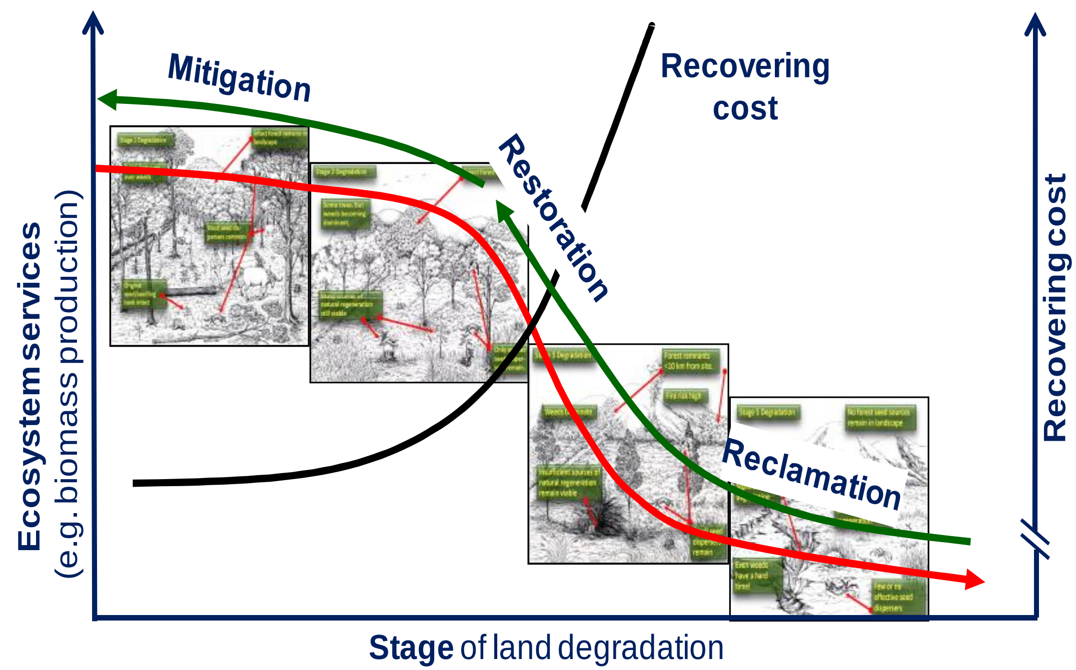
Main points

- 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

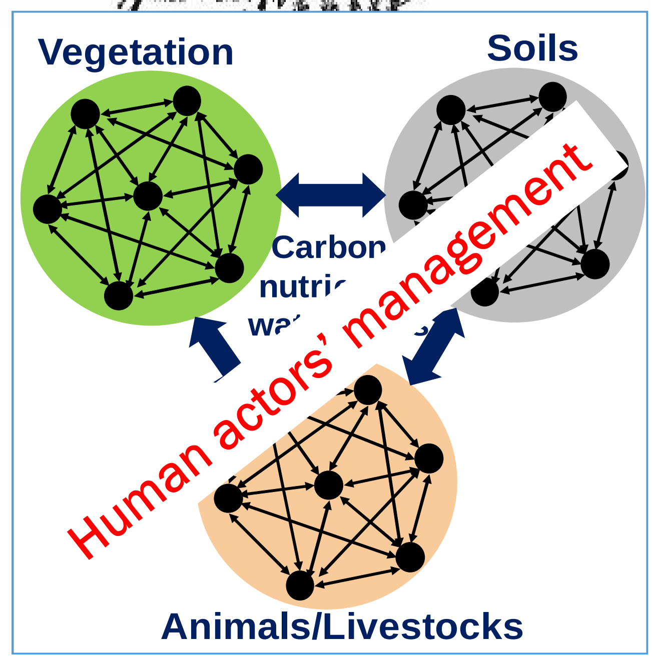


Source: Le (2012) 1st Global Soil Week; illustrative pictures from Elliott et al. (2008)

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 a grand 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
- Eco-efficiency: produce more with less inputs, externalities, risks and improved potentials
- Social equity: in both landscape services' benefit and restoration/protection responsibility

A resilience view of transitions to sustainable intensifications

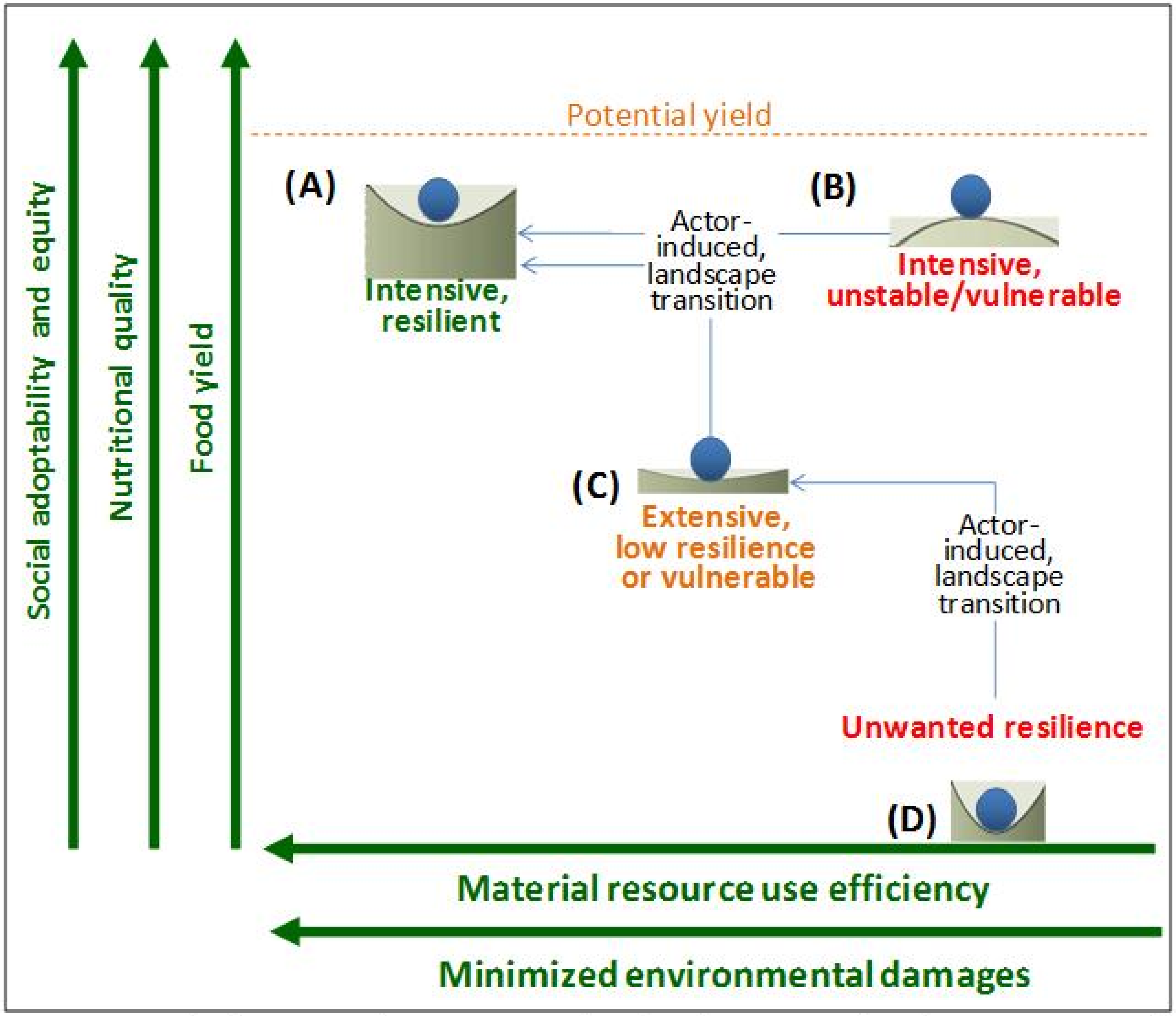


Figure 1. Multi-dimensional expectations (axes) and transitional pathways to sustainable intensification (SI), i.e., regime (A).

Source:
Le, Tamene et al. (in prep.)

Resilience view of transitions to sustainable intensifications

- Eco-efficiency is as one of essential aspects considered in sustainable intensification
- Shifting-up efficiency frontier curve as transitioning into improved stability domain

Source:
Le, Tamene et al. (in prep.)

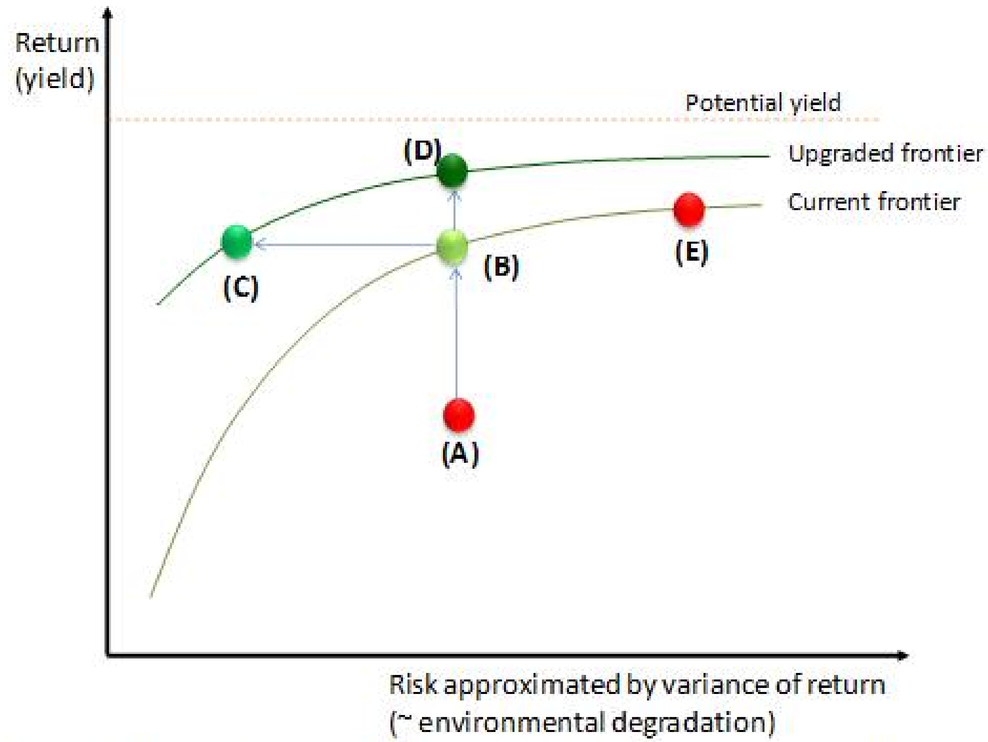
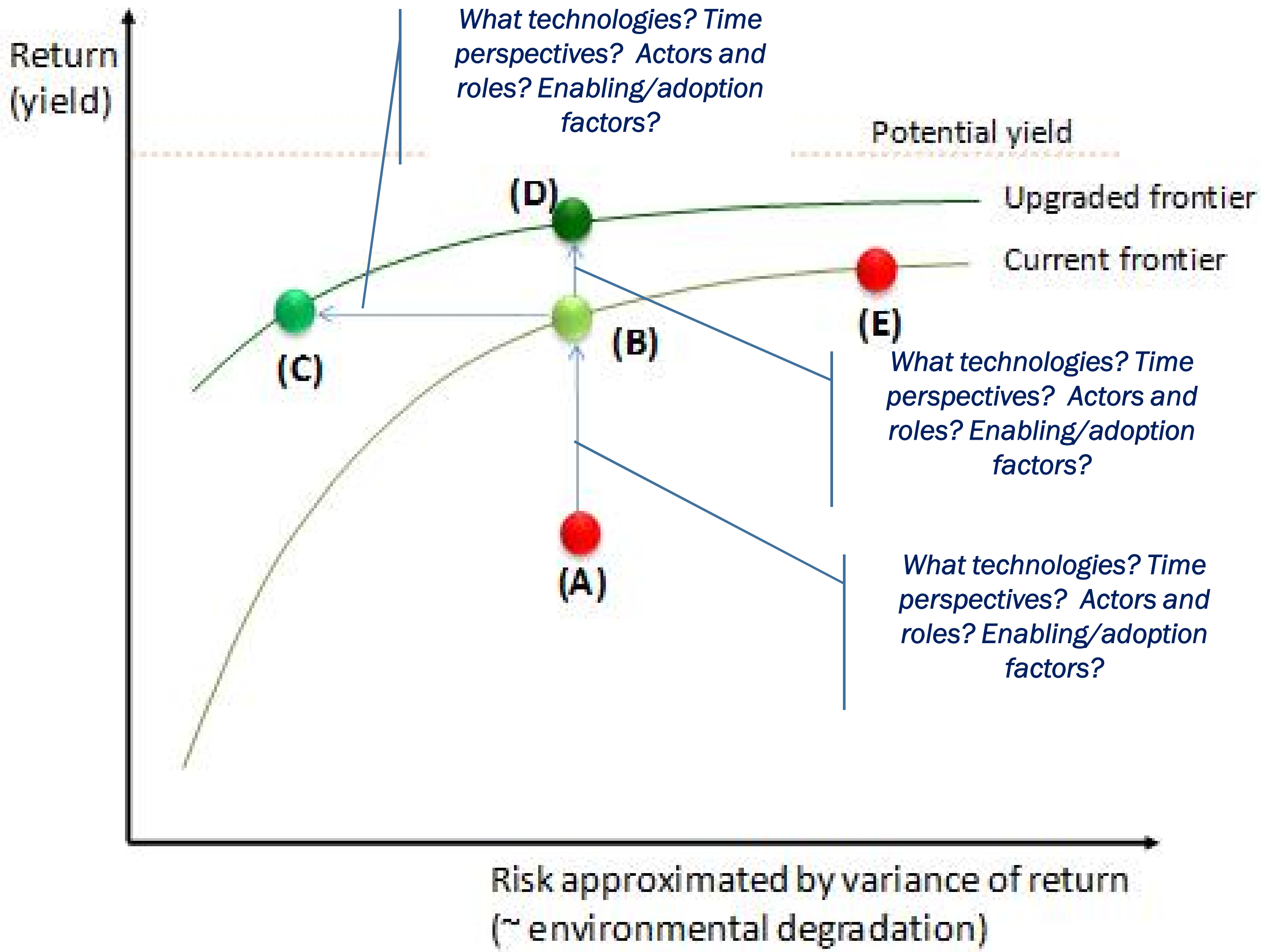


Figure 3. Pathways of transitions to eco-efficient intensification: A→B: improving productivity given the same risk level (e.g. improving farming practices within the given resource and technological regime). Then, from state (B) the transitional options can be: B→C: moving to new efficient frontier to reduce risk (e.g., diversification of crop patterns, integrated pest management or integrated nutrient management), or B→C: increase productivity with no further negative environmental impacts process by applying radical technological change (new crop varieties with high nutrient-use efficiency), building up soil fertility with strong recycling effort. System tendency B→E should be avoided as environmental damages once done is difficult to undo.

Resilience view of transitions to sustainable intensifications: human actor-driven processes

- Where is the starting point of your systems? Typology needs!
- What technologies needs? Time perspective? Human actors' roles? Enabling and adoption factors?



Source: Le (2014)

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)

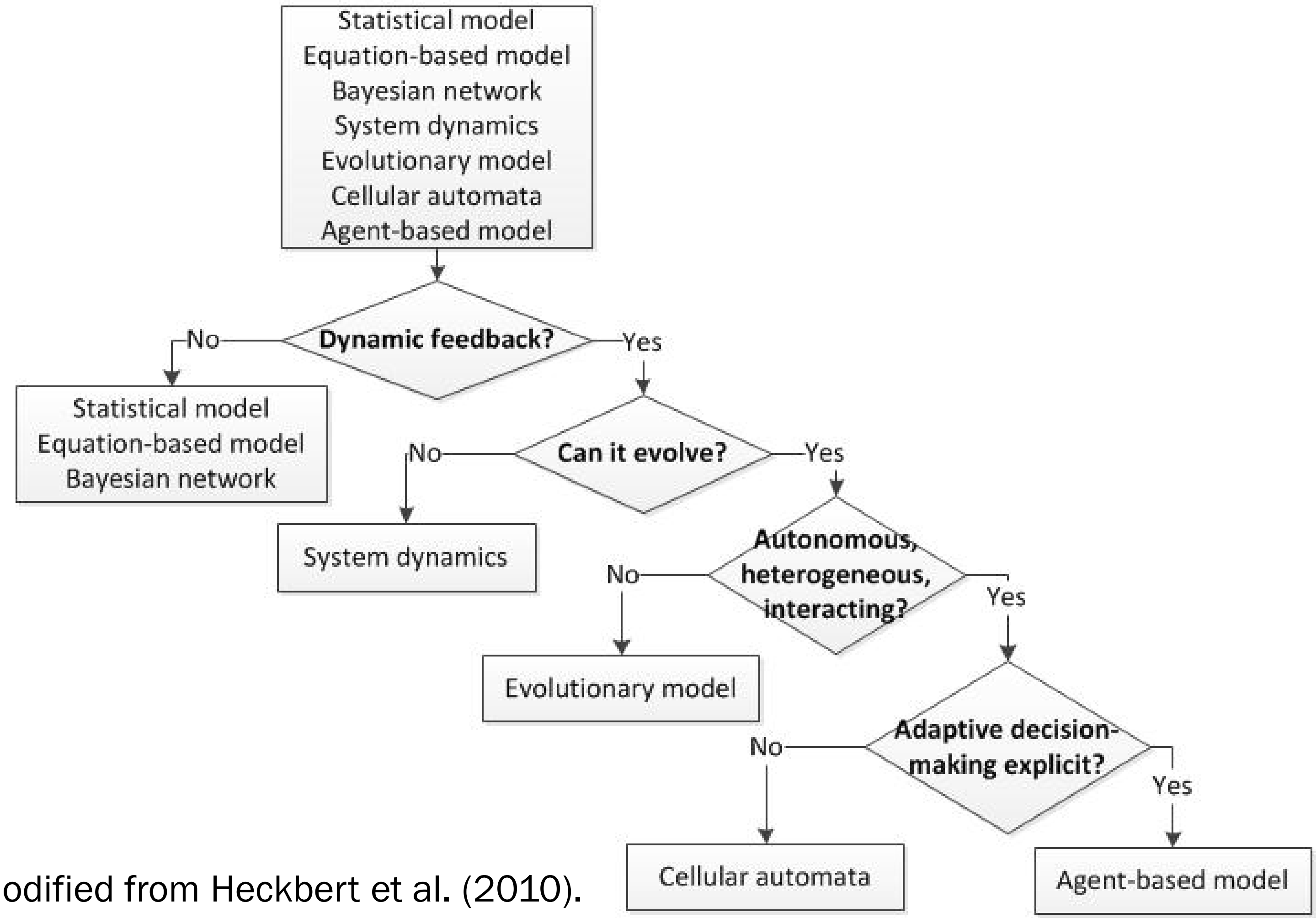
Problem	Method requirement
Flexible (not fixed) feedback loops genetated by actors‘ decisions	Actors' behavior explained
Actors‘ decisions changable along learning	Relevant learning process captured
Heterogeneity as important source of buffering, adaptive capacities	Within- and between- farm heterogeneities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

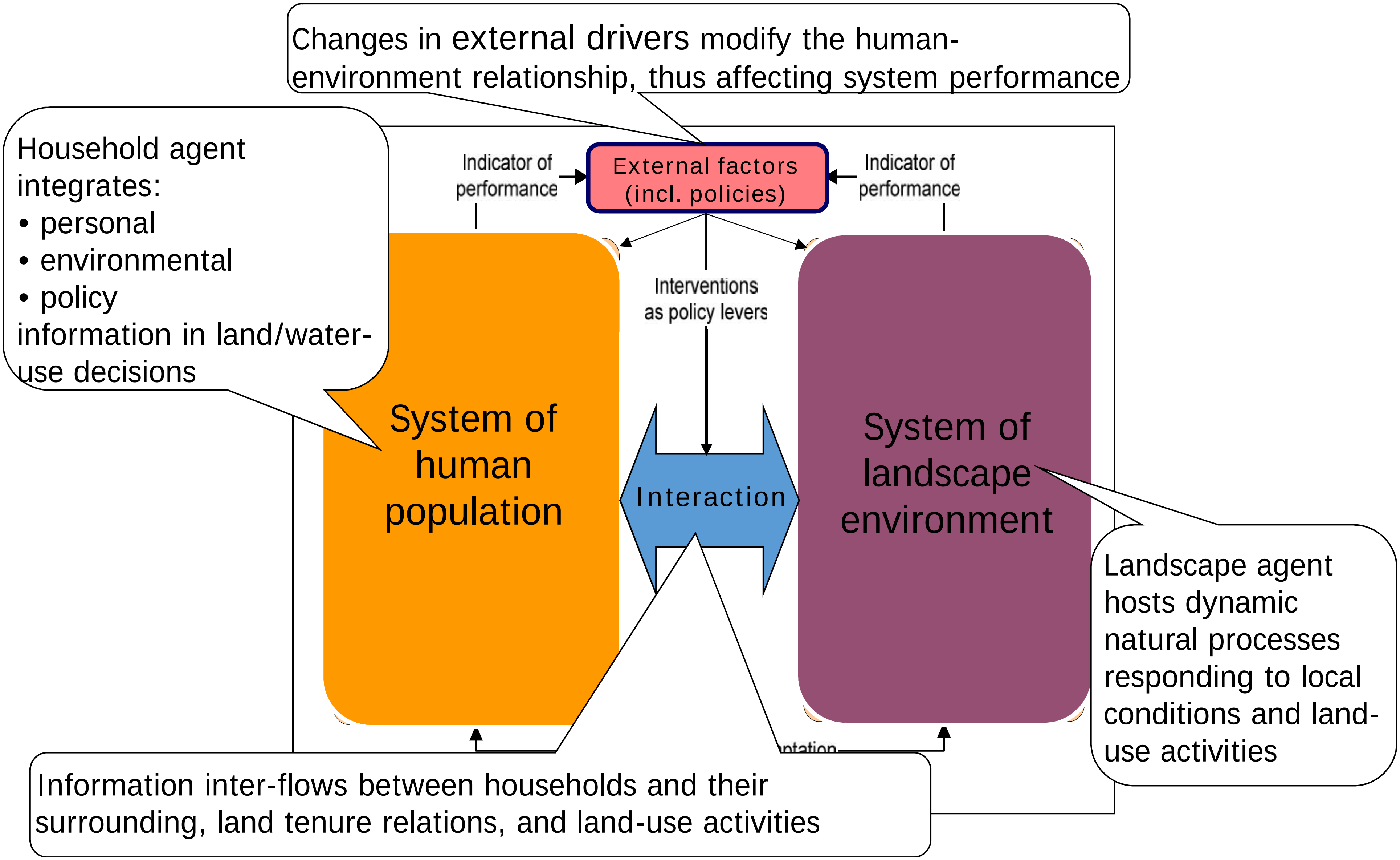
Table 1. Comparative assessment of contemporary farming system modeling approach with respect to criteria for farm resilient research. Note: publications in parentheses are as relevant examples).

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



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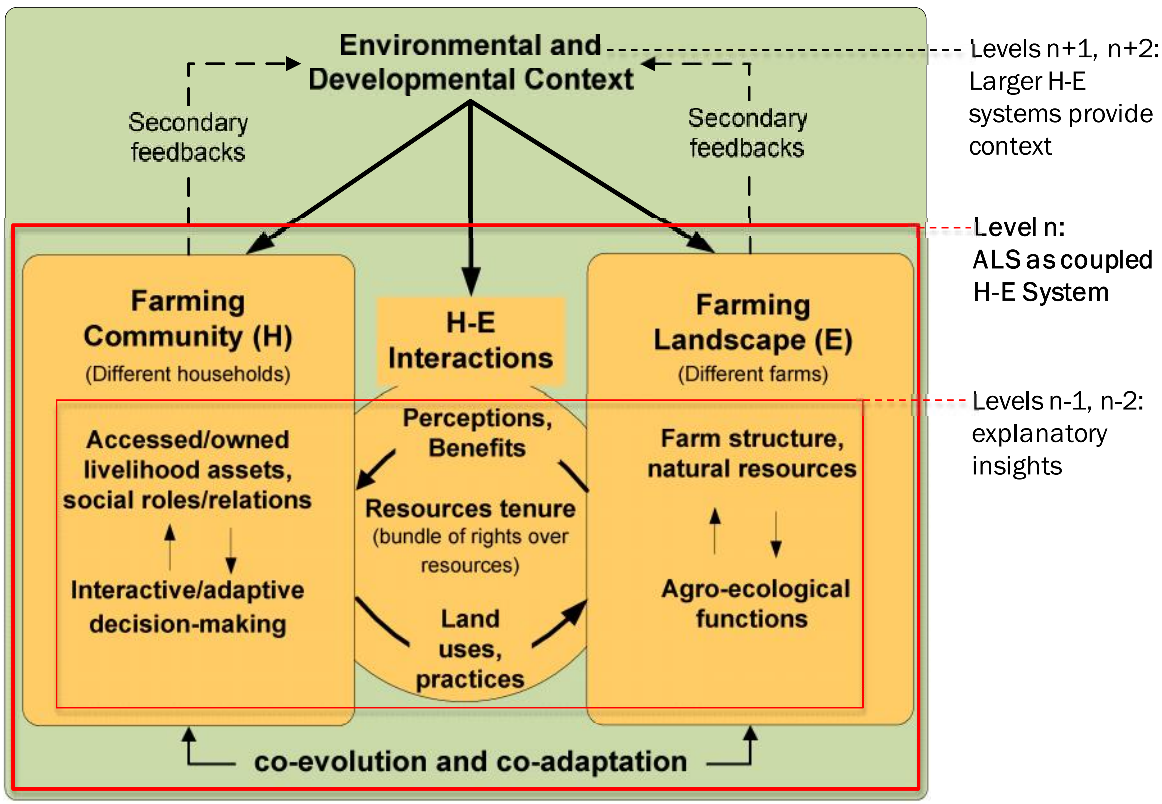
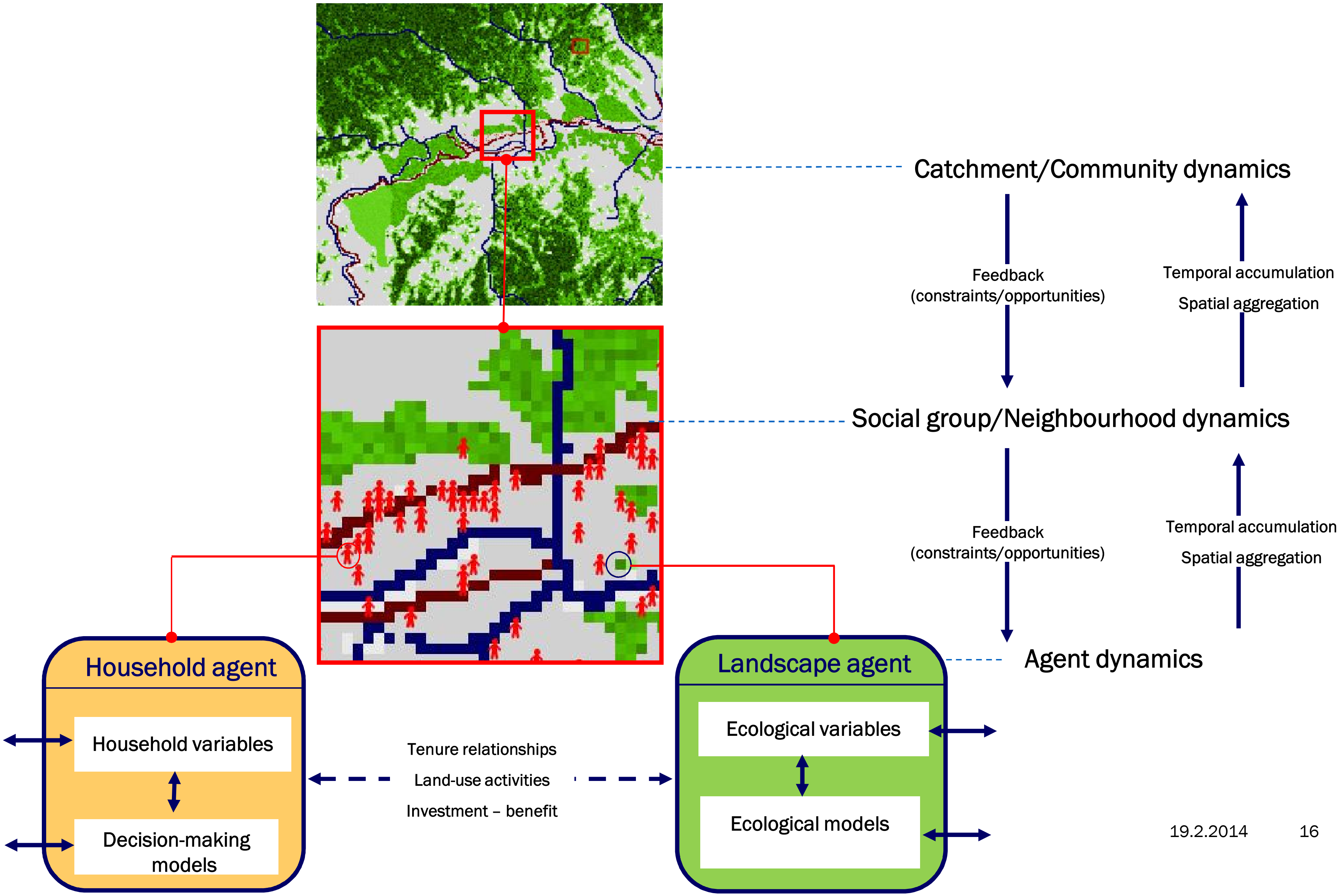
LUDAS framework for modeling coupled agrarian landscape-community level



Cross-scale, generative feedback loops in LUDAS



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

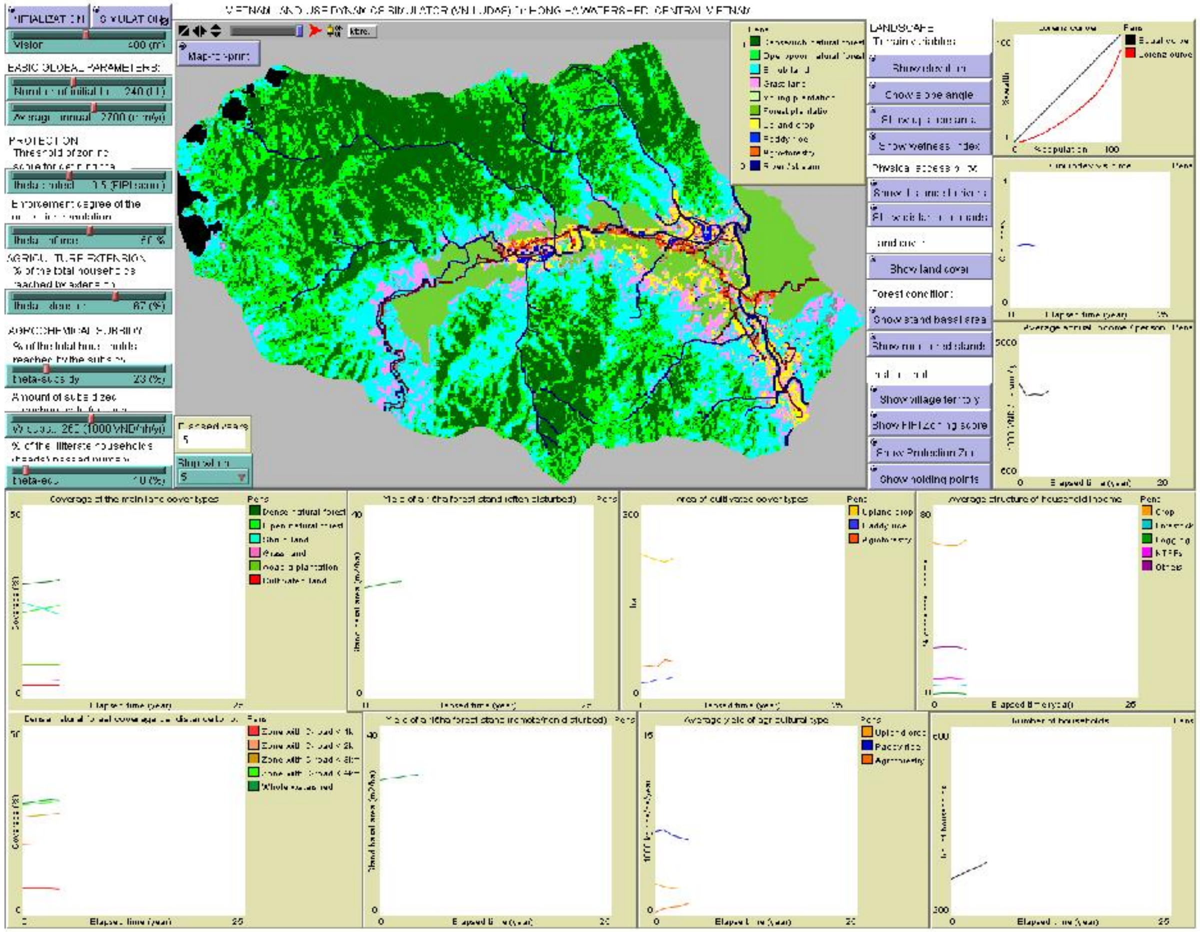
- User-friendly interface allows and stimulates stakeholder participation

  - 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

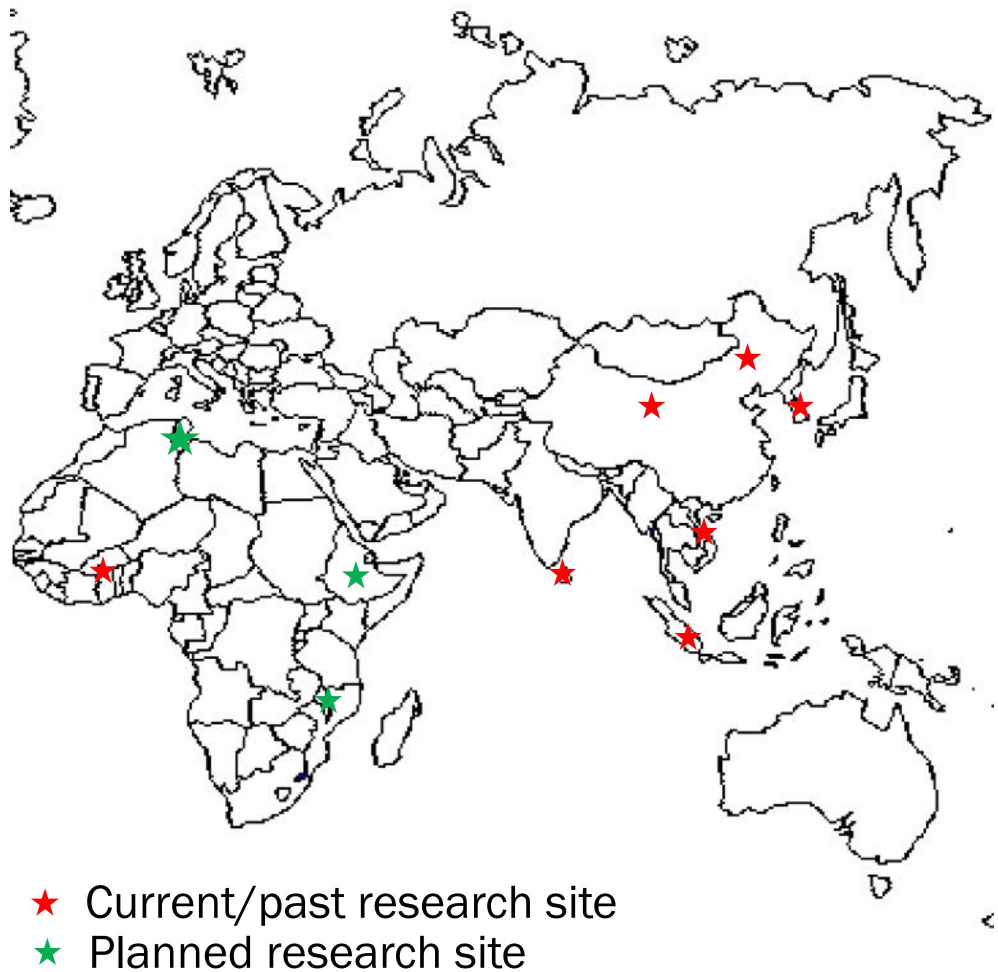
Context-based specifications and applications of the modeling framework

In different social-ecological regions:

- Tropical forests
- Semi-arid zones
- Coastal zones

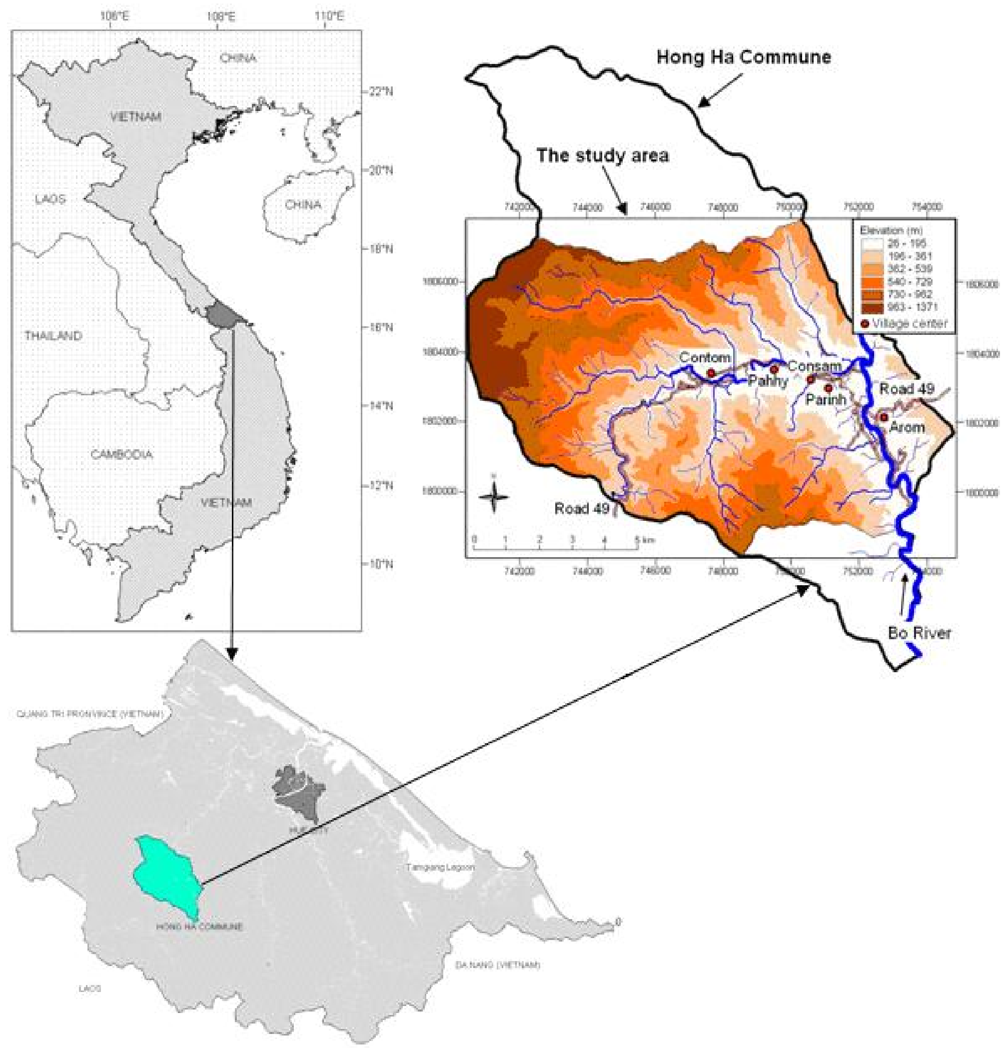
By different research teams:

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



Application of LUDAS for Hong Ha catchment (Vietnam)

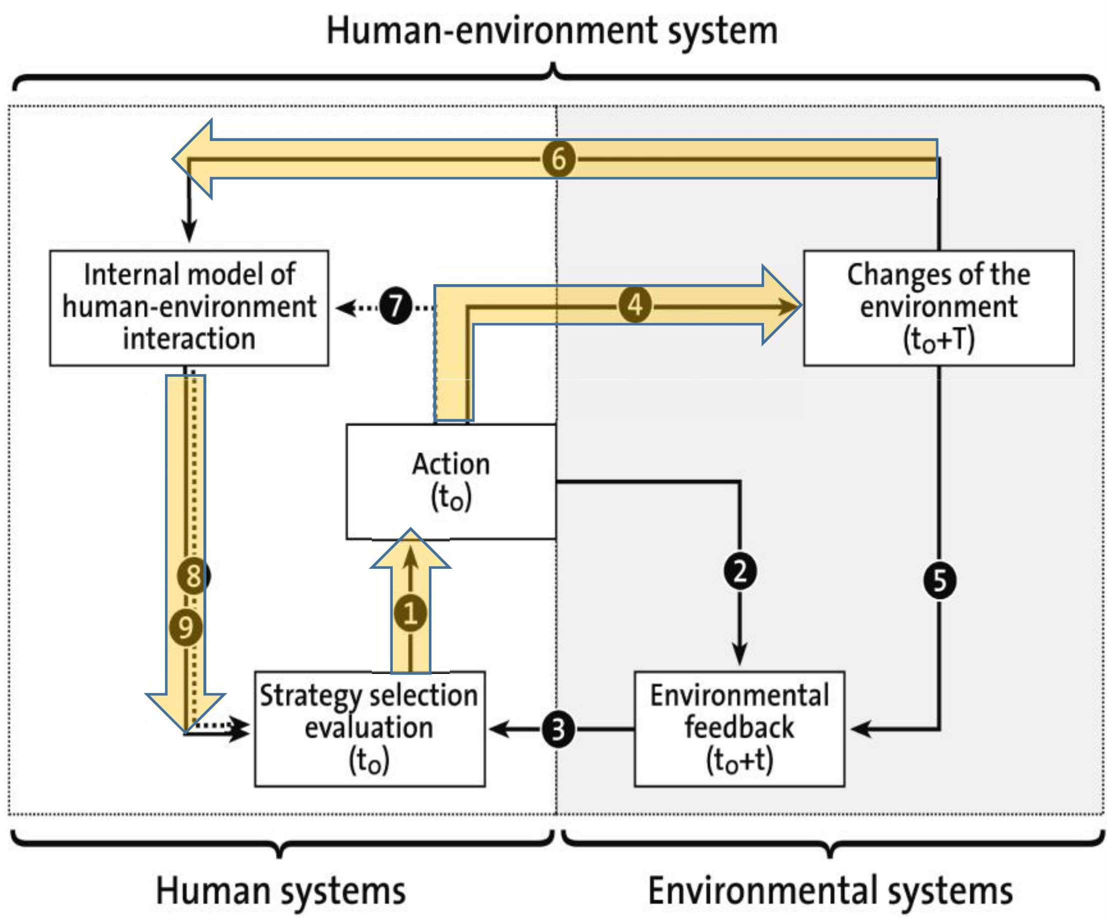
- Size of the study area: 100 km^2
- Protected mountain watershed in tropical forest zone
- 240 households who are agriculture- and forest- dependents
- Puzzles in policy decisions in:
  - Forest protection zoning
  - Agricultural extension
  - Agrochemical subsidy



Thua Thien – Hue province

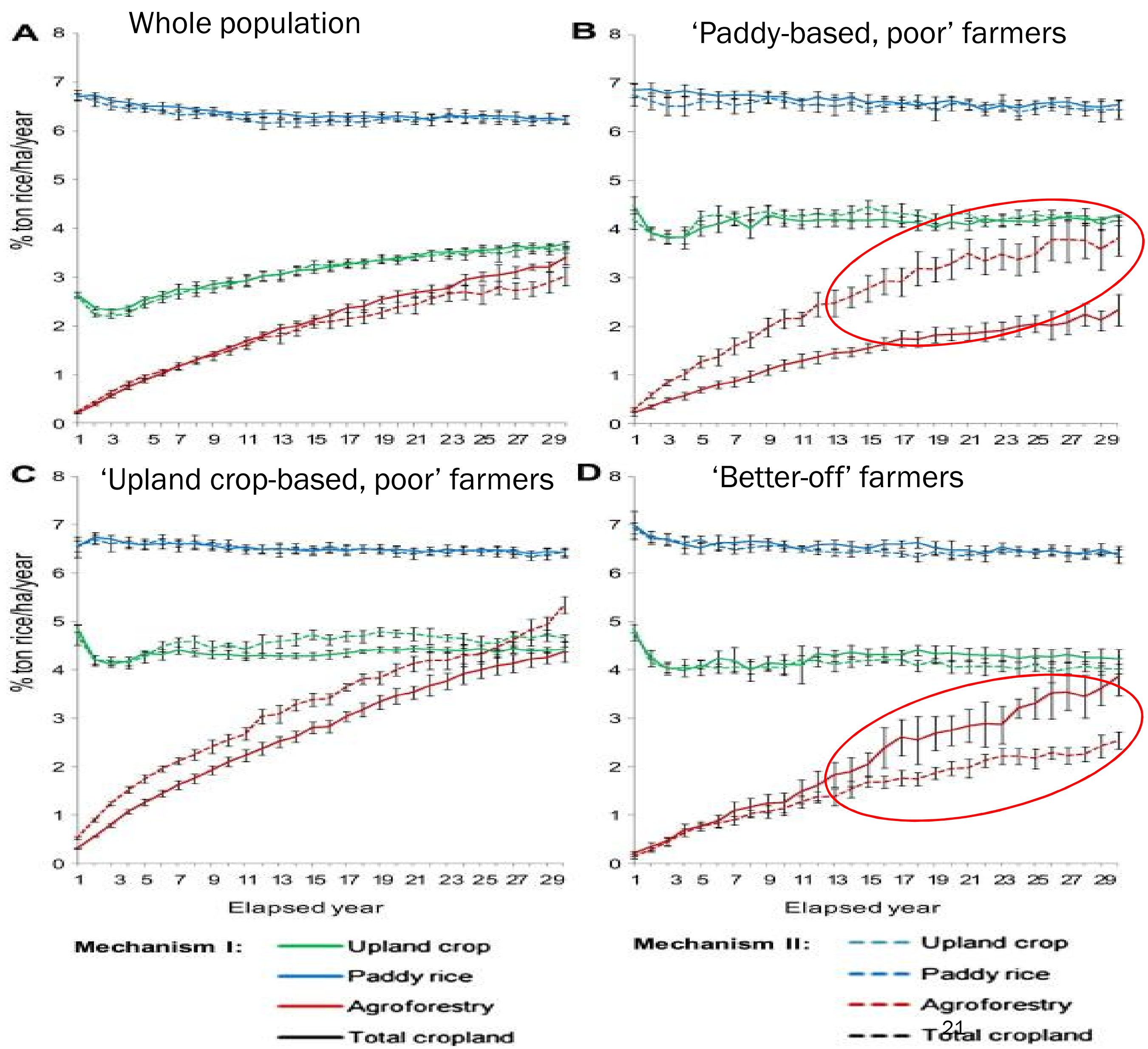
Test ex-ante impacts of farmers' adaptive learning

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

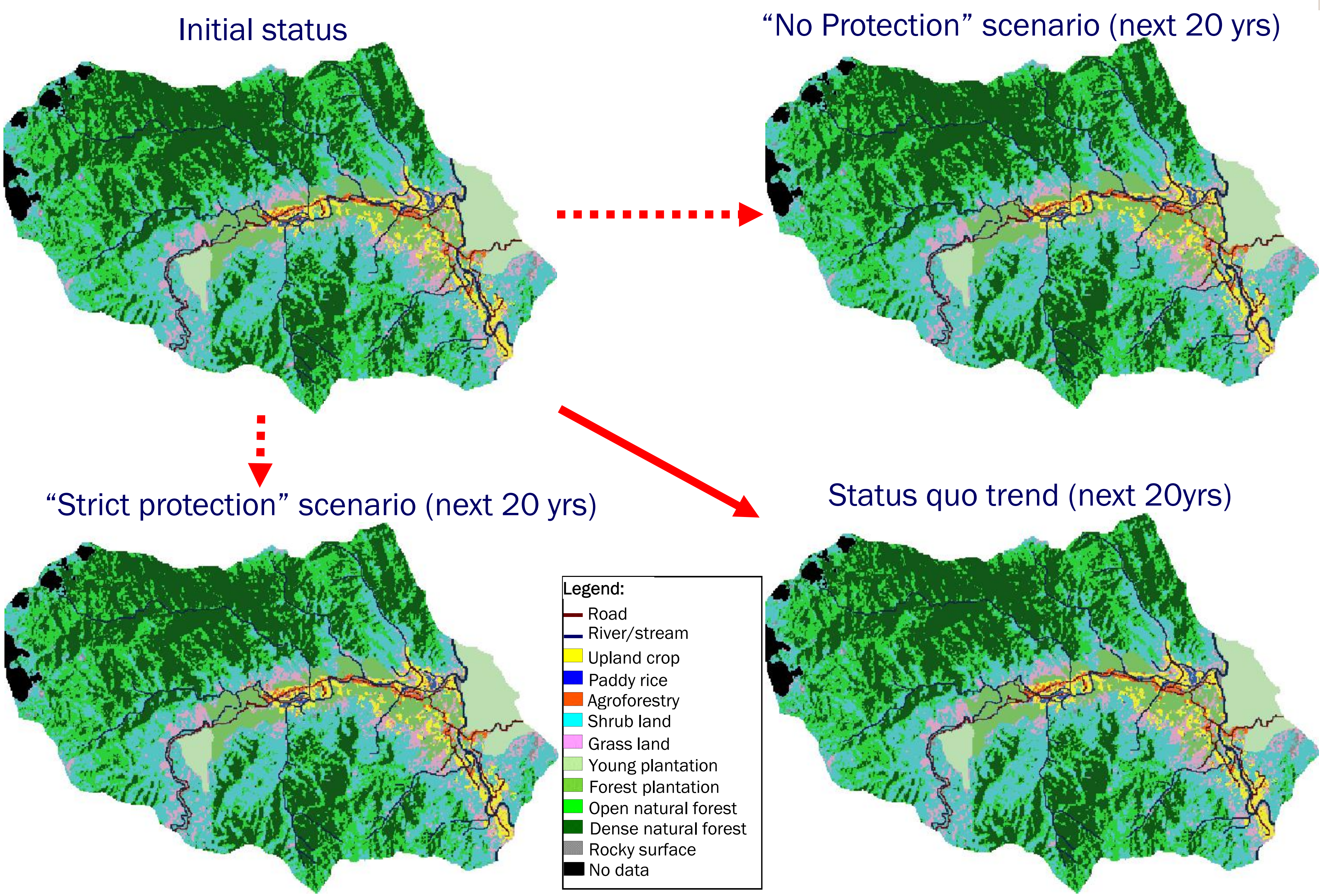


Le et al. (2012). *Environmental Modelling & Software* 27-28: 83-96

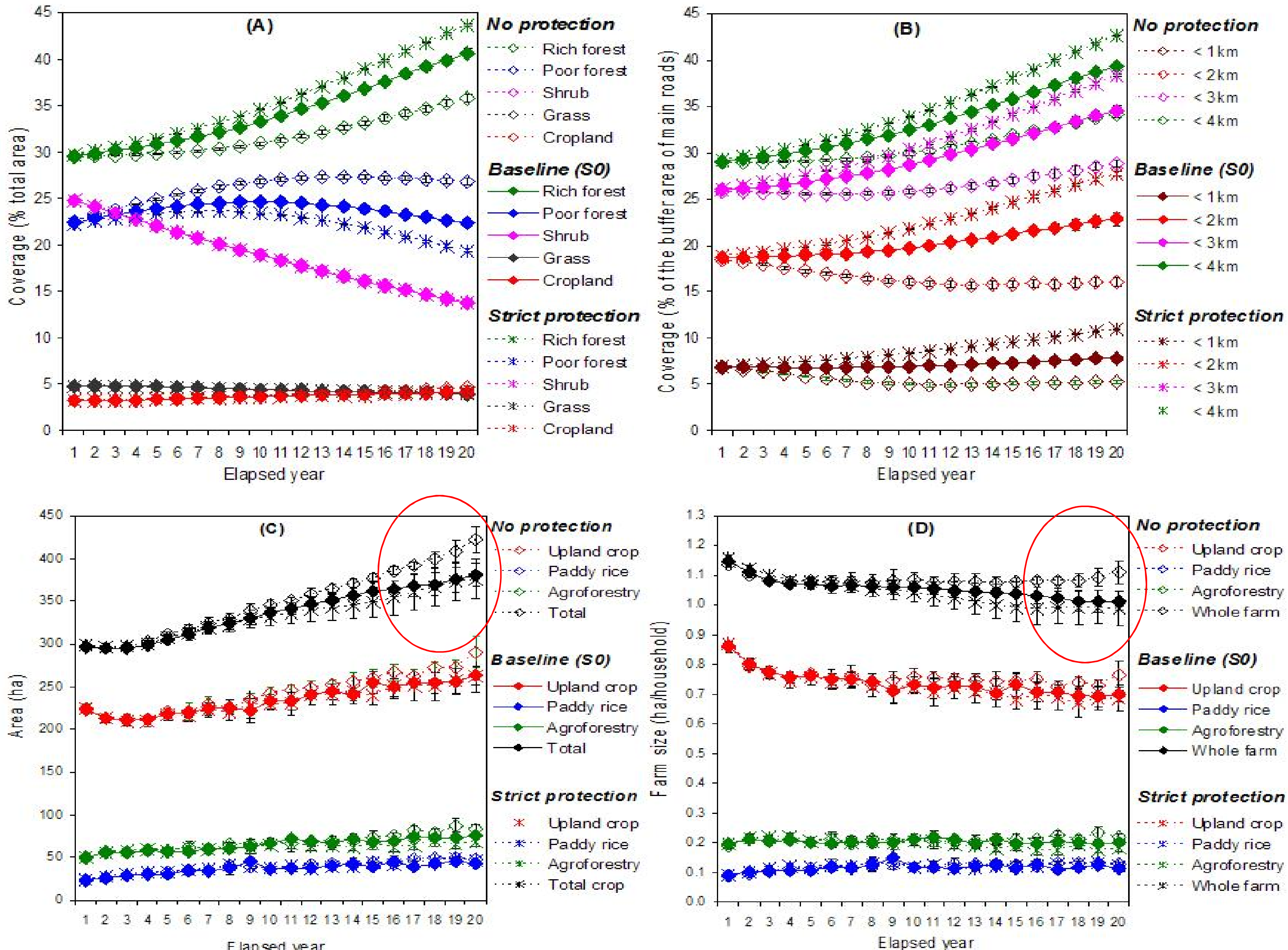
Pilot application of VN-LUDAS: Potential impacts of land-use policy changes on community-landscape dynamics

- 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



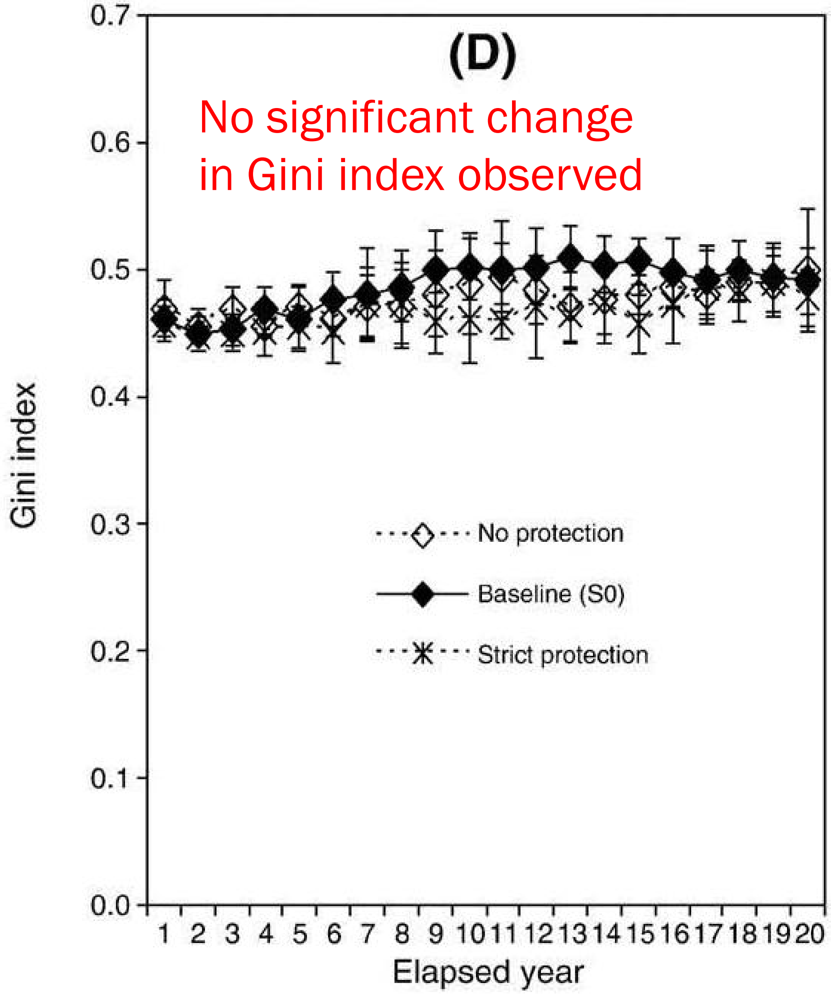
Delayed impacts of protection zoning on farm size

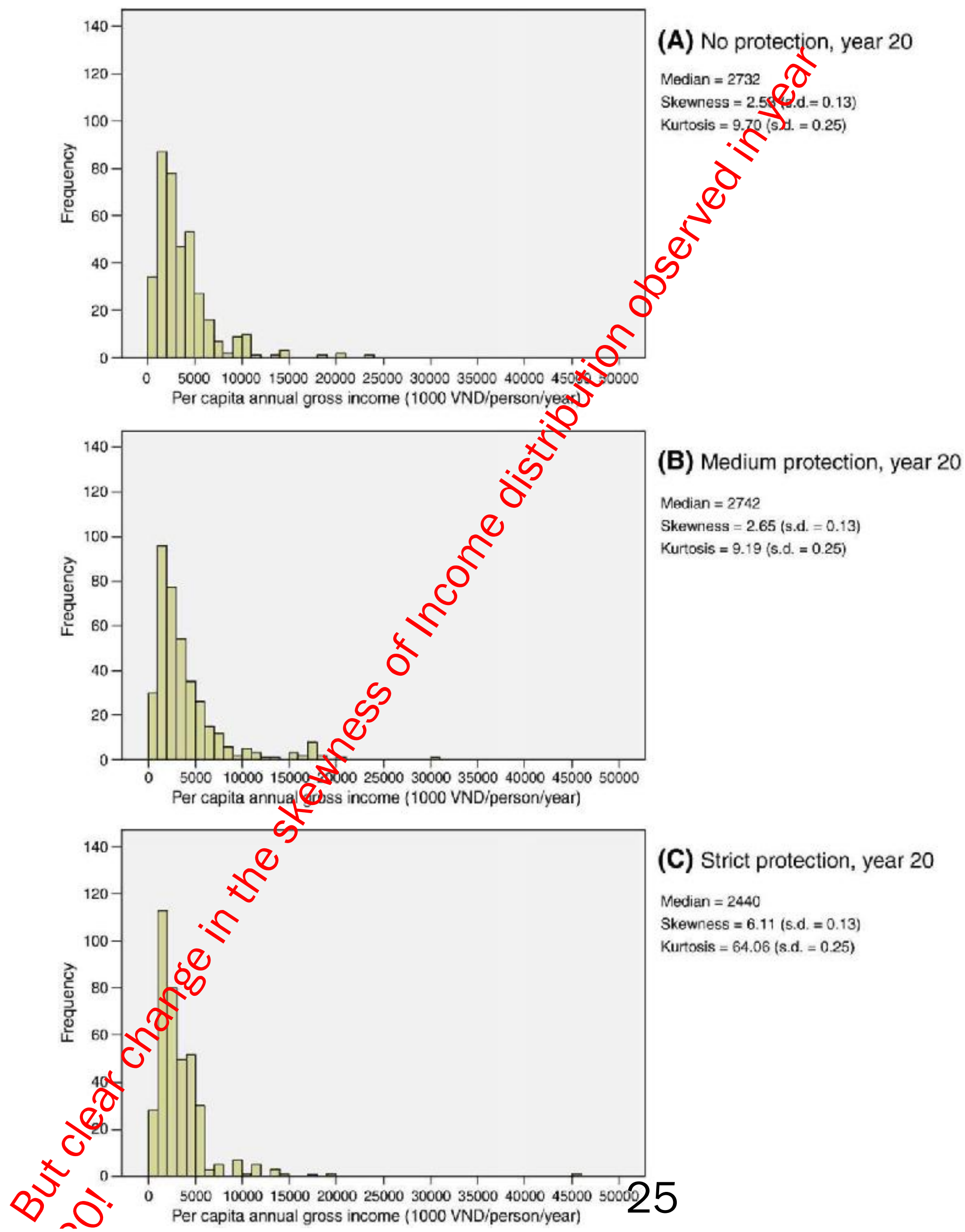


Source: Le at al. (2010) Ecological Informatics 5: 203-21

Delayed impact of protection zoning on income equity

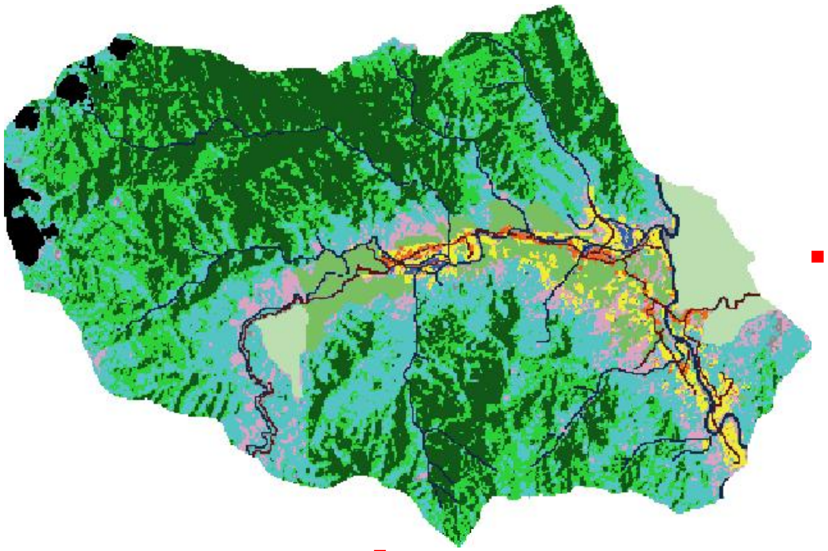
Source: Le et al. (2010)



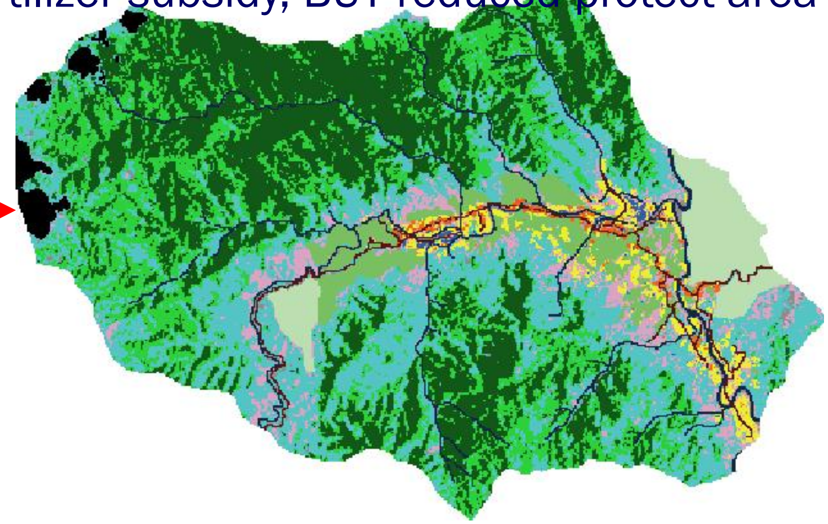


A sound combined policy intervention

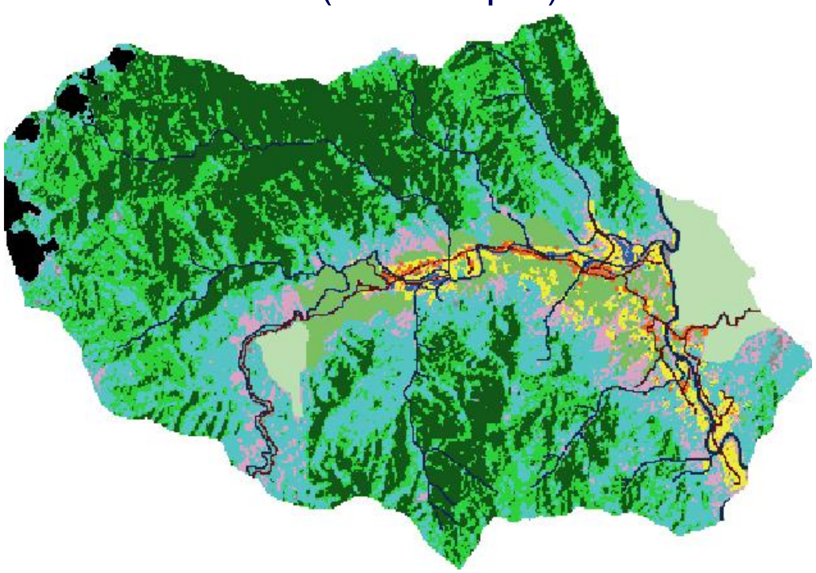
Initial status

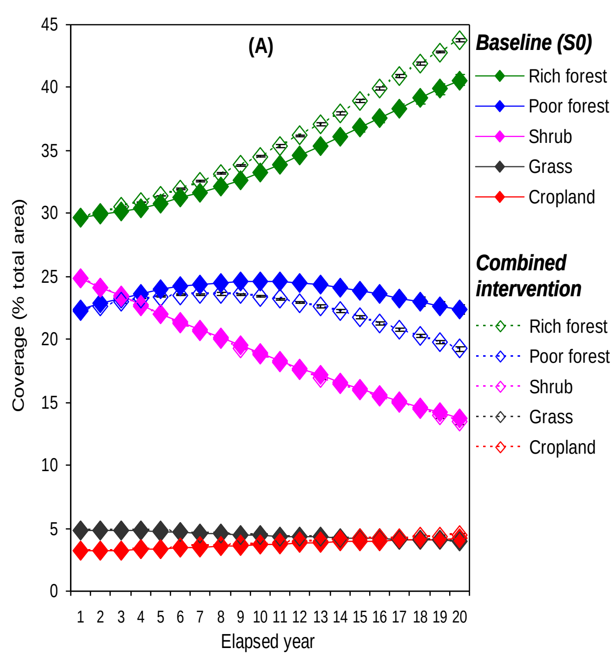


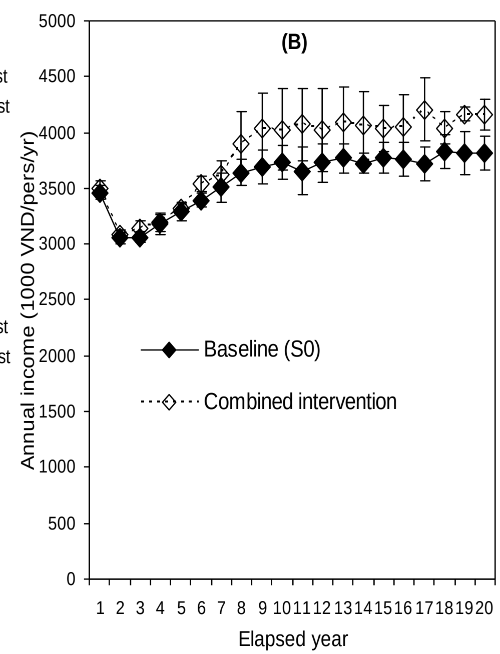
More law enforcement + arg. extension
+ minor fertilizer subsidy, BUT reduced protect area



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
  - Connected value chains

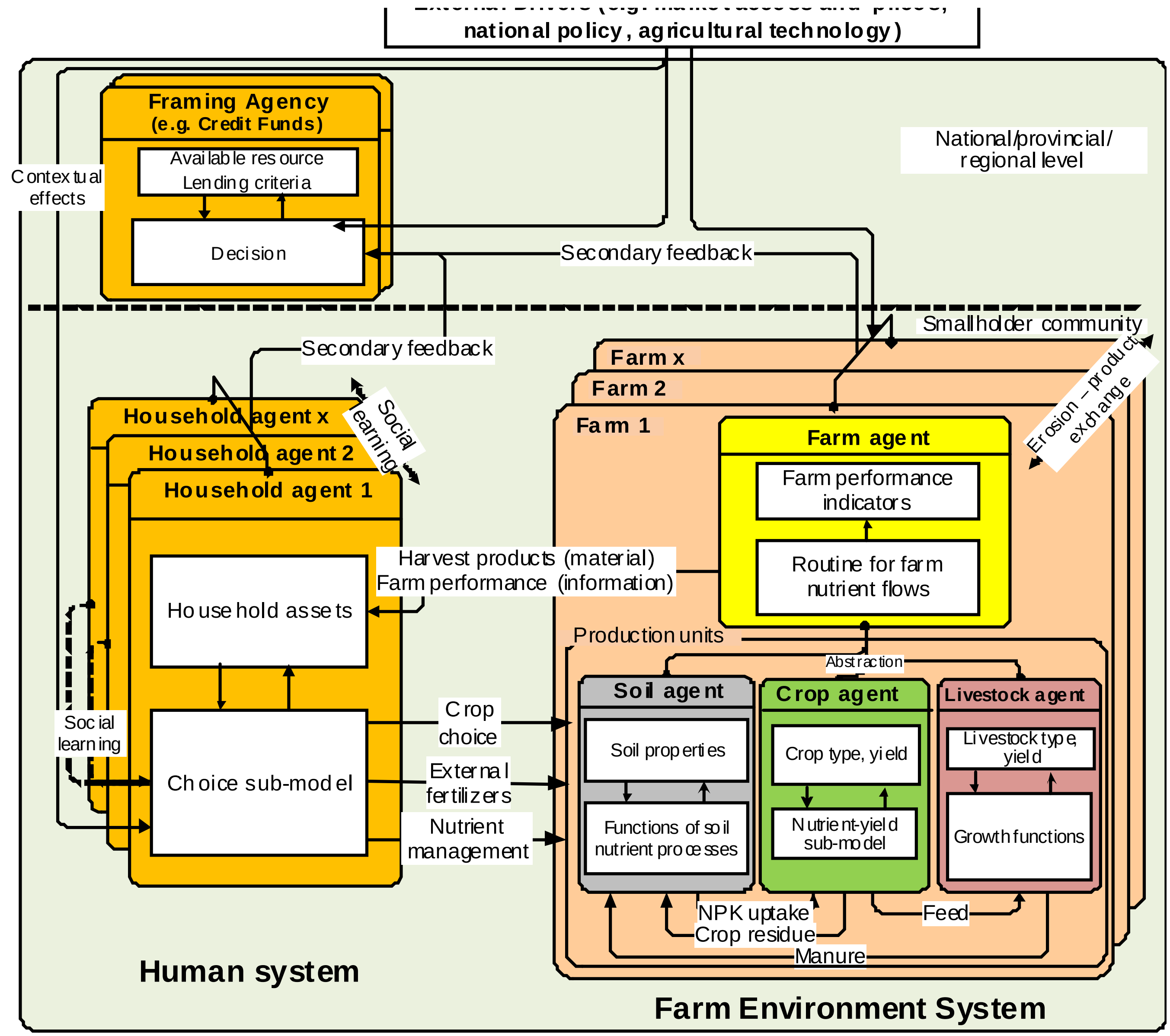
  → Grand need and challenge: Coupling place-based (agro-ecology) and flow-based (supply, value chains) processes

- Resilience-relevant outputs
  - Onset of regime shifts
  - Buffering capacity indices
  - Adaptation indices
  - Transitions between farm types

- Systematic, rigorous model validation

New version capturing farms' heterogeneities and metabolism

- 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



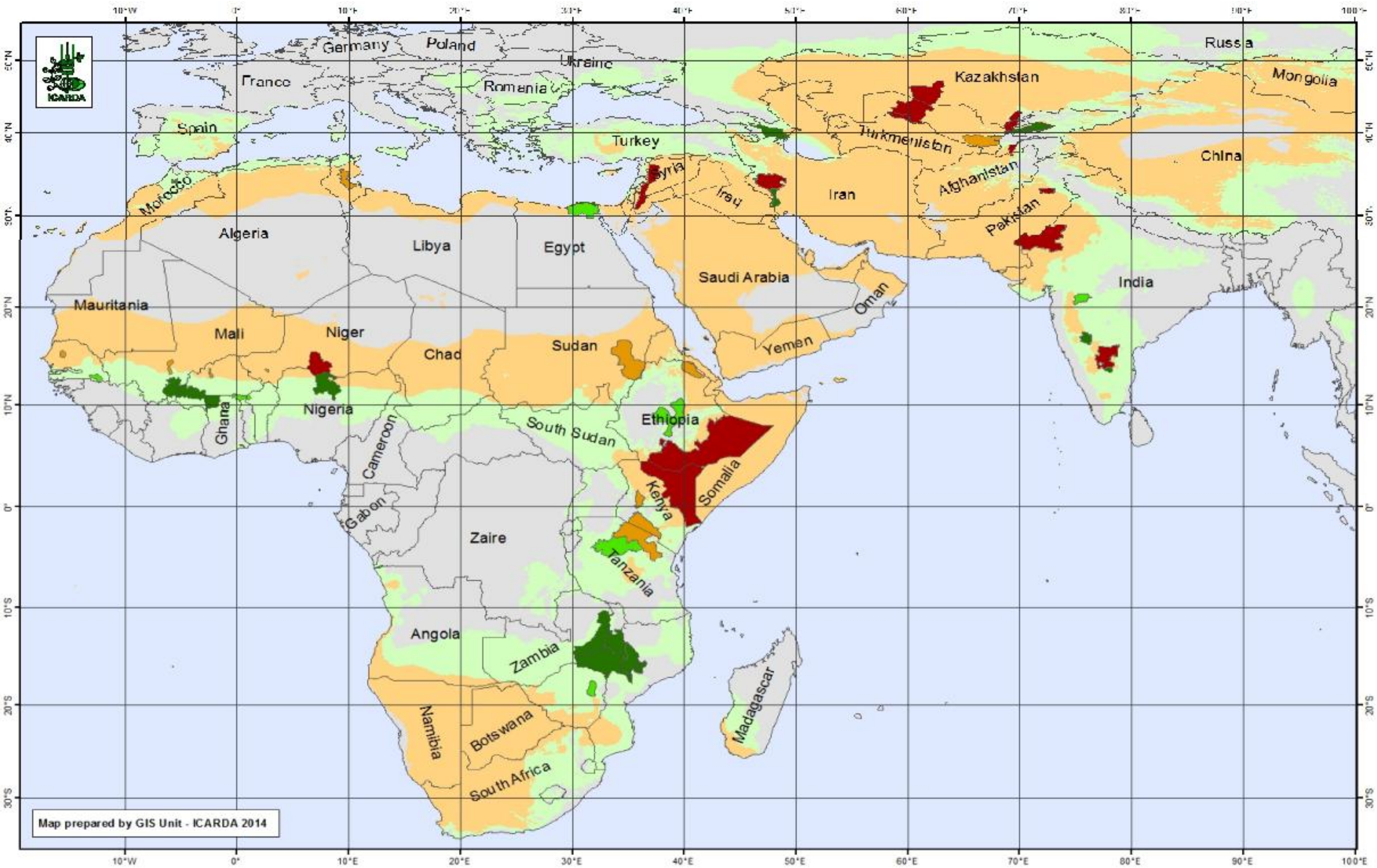
Source: Le et al. (2012)

On-going research in different regions

- West Africa: Mixed rain-fed systems in Burkina Faso (CRP-DS, WASCAL)
- Eastern and Southern Africa: Mixed rain-fed systems in Malawi and Ethiopia (CRP-DS, CIAT-Malawi)
- Southeast Asia: Central and North-Western Mountains of Vietnam (past Ph.D study projects, follow-up currently self-funded)

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.

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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