# Maps and Locals Workshop Report
## HJ Andrews Experimental Forest
## June 5-8, 2011

*Submitted by Nathan Sayre, University of California, Berkeley*
*with Gary Kofinas and John Harrington (workshop co-conveners)*

**Introduction and Objectives**

The second Maps and Locals (MALS) workshop was held at the HJ Andrews Experimental Forest outside Blue River, Oregon, June 5-8, 2011, and involved participants from 12 LTER sites. (See Appendix 1 for participants; see Appendix 2 for agenda.)

The main objective of the 2011 MALS workshop was to draft a paper synthesizing the findings of the project over the past two years, including data from 14 sites (see Appendix 4 for draft). The paper will be submitted to *Frontiers in Ecology and the Environment* for publication. The workshop also continued to assess findings and methods on mapping and for integrating local knowledge with spatial analysis, and began developing a proposal to compare overlapping drivers of change across LTER sites. The workshop provided an opportunity for face-to-face exchange of ideas on methods and research, and to review the spatial analysis previously completed by Robert (Gil) Pontus at Clark University, and the recently completed Masters thesis on local knowledge and land use change around the HJ Andrews Experimental Forest by Tim Inman of Oregon State University.

**Background**

MALS is funded by LTER Social Science Supplement grants of the National Science Foundation with the following objectives:

- To use spatial representation of land cover and land use to identify patterns of landscape change in regions in and around LTER sites
- To integrate local ecological knowledge (LEK) and other existing social data with spatial analysis into theories and models of social-ecological change to understand their implications to human livelihoods and wellbeing.
- Participating LTER sites emphasize these activities to varying degrees with the goal of making cross-site comparisons and setting the stage for future cross-site comparative studies.

The MALS project and the workshop were motivated by the dramatic and rapid changes being observed across the LTER network and the need to understand these changes in the context of a “coupled social-ecological systems” (SES) framework. The current state of SES science suggests there is a critical need for more robust interdisciplinary approaches to investigating human-environment interactions. Following from these needs, the MALS group hypothesized that the integration of spatial analysis (maps) and local knowledge provides an enhanced approach for 1) understanding change, 2) accounting for its complexity, 3) and achieving salience in research.

## Workshop Transactions

*Nine New Methods for Spatial Analysis of Land Change - Gil Pontius et al. at Clark University:*

On the first evening, Gil Pontius reviewed nine new methods developed by his group at Clark to deal with the issues that arose from MALS spatial analysis. These nine new methodological innovations produced nine manuscripts at various stages of development by Pontius et al.

We now have methods to address spatial analysis in MALS, including techniques to:

- measure the stability of land transitions over time
- aggregate categories strategically to form a small number of important categories
- compare various sites concerning the stability of land transitions
- distinguish between sprawl change and turnover change
- quantify the amount of error that could explain the differences in maps
- extrapolate categorical transitions over time
- test whether changes tend to occur at the same places in consecutive time intervals
- show graphically the comparison between a rank map and a Boolean map
- 'kill' the popular Kappa statistic (Pontius and Millones 2011)

*Maps and Locals (MALS): An experiment in integrating spatial analysis and local knowledge across LTER sites to study the dynamics of social-ecological systems – DRAFT for Frontiers in Ecology and Environment*

The meeting began with a subset of MALS researchers in Portland June 4th. Nathan Sayre, John Harrington and Gary Kofinas met at the Radisson Airport Hotel to draft a first working version of the MALS Synthesis Paper. This working draft was sent out for participants to have read as a basis for discussion on the first full day of the workshop. The discussion that followed on Monday June 6 focused on outlining the findings of the MALS project thus far. Gary Kofinas presented on the interview findings on local knowledge research across participating sites, which formed the basis for small breakout groups to draft specific sections on MALS findings regarding:

- Collaborative and Cross-site research process
- Methods and Mapping
- Emergent Findings from Local Knowledge (LK) Research

*Discussions on research questions, methods, and common protocols*

The third task of the workshop was to develop a conceptual and methodological framework for future cross-site SES research within the LTER network. This discussion occurred on the morning of June 7th. We identified a number of common drivers of change across our sites:

- *Development* is a common and immediate driver of change across many sites, and all sites have been affected by the current economic crisis, including the related effects of high oil prices (BNZ and ARC).
- *Economic boom – bust cycles* were identified as a key broad-scale driver of local change
- *Climate change* – On some sites, climate change is the key broad-scale driver of local change, on others, climate change effects are less immediately felt than economic swings

The ensuing discussion produced an outline for moving forward with MALS research. Please see Appendix 3 for this outline.

MALS workshop participants meeting in the HJ Andrews Experimental Forest conference facility. (Photo by Gary Kofinas.)

## Appendix 1:
## Workshop Participants

| First | Last | LTER site |
|---|---|---|
| Hannah | Gosnell | HJ Andrews |
| John | Harrington | Konza |
| Tim | Inman | HJ Andrews |
| Barbara | Nolan | Jornada |
| Laura | Ogden | FL Coastal |
| Gil | Pontius | Plum Island Ecosystems |
| Nathan | Sayre | Jornada |
| Annie | Shattuck | Jornada/UC Berkeley PhD Student |
| John | Van Castle | LTER Network Office |
| Abigail | York | Central AZ-Phoenix |
| Patrick | Bourgeron | Niwot |
| Gary | Kofinas | BNZ and ARC UAF |
| JP | Schmidt | GA Coastal |

**Appendix 2:**
**Workshop Agenda: MALS June 5-8, 2011**
**HJ Andrews Experimental Forest**
http://andrewsforest.oregonstate.edu/

**Saturday June 4th**
Gary, Nathan and John convene at Radisson Hotel by the Portland airport to draft paper manuscript on MALS Local Knowledge work

**Sunday June 5th**
Morning: GK, NS, and JH complete draft of MALS paper, print out copies + send as email attachment

By 2:00: Gather at Portland Airport, travel to Andrews, arrive by 6:30 p.m.

7:00 p.m.: Dinner
8:00 Nathan and Gary: Introductions and goals for the workshop as a whole
Gil presents on the mapping work: status, etc.
Casual discussion about integrating GIS and LK

**Monday June 6th**
7:30 a.m.: Breakfast
8:15: Read draft manuscript
8:45: John Harrington: Review of existing comparative SES research across very different sites
9:00: Gary: Presentation of Alina's interview research findings
9:30: Nathan/Gary/John: Presentation of MALS manuscript

10:15: Break

10:30: Discussion of manuscript: overall message, big picture ideas and themes
11:15: Individuals revise or write text of a specific topic or piece of the paper

12:00 noon: Lunch

1:00 p.m.: Break into teams to work on the three workshop protocols:

1. How to compare LTER sites as SESs: gradients, frameworks, data types
2. How to collect comparable LEK across LTER sites
3. How to incorporate social scientific data into GIS/mapping tools

2:30: Break

3:00: Each team presents its protocol results
3:45: Whole group discussion on workshop protocols

5:30: Break—free time

6:30: Dinner

7:15: Barbara Bond, PI of the HJ Andrews LTER: Presentation about HJ Andrews

**Tuesday June 7th**
7:30 a.m.: Breakfast

8:15: Grad students reflect on the previous day: What did we say, what questions do they have
8:30: Workshop the paper as a single group

10:15: Break

10:30: Discussion of current/future local knowledge research at participating sites
11:15: Discussion: How to convert the protocols into proposal(s) for outside funding
Which sites are interested in participating?
What do they need to make it work?
Who's prepared to do what to get it done?

12:00 noon: Lunch and Presentation of Masters Thesis Research by Tim Inman

1:00: Field trip
Visited the nearby town of Blue River, which was a successful timber producing community through the middle 20th century based primarily on timber concessions on the surrounding Willamette National Forest, but has declined in recent decades as the concessions were reduced to near-zero, due in significant part to spotted owl related restrictions.

1:30 We met at the community's new athletic track, a source of considerable local pride and built with donations from local residents and businesses. It provided a view of privately-owned timber lands that had recently been clear-cut and replanted. Our speaker was the local USFS forester, who gave us a talk about forestry practices on the National Forest and answered our questions. We then met with Kathy Keable, who runs the HJA facility and also serves on the local school board. She described how economic decline and falling enrollment has impacted the community over the past 35 years.

3:15 We drove up into the National Forest and took a short hike to Tomolitch Pool, a site where the McKenzie River reemerges from underground. It had previously been a waterfall with above ground flow, but that dried up after a dam was built upriver.

5:00 We visited the Belknap Hot Springs, a developed private hotel/spa on the banks of the McKenzie.

6:30: Return to HJ Andrews for BBQ Dinner

7:30 Discussion of proposed common protocols and research question for proposal for large-scale cross-site comparison research
9:30: Discussion/evaluation of workshop

**Wednesday:**

7:30 a.m.: Breakfast
9:00 (or later if feasible): Depart for PDX
Box lunches will be available for people to take with them

Meeting with the local Forest Service forester to learn about management practices and timber issues on regional forests. The athletic track where we met is newly built and a source of great local pride. Note the recently clear-cut area on private timber land in the background. (Photo by Nathan Sayre.)

## Appendix 3:
## Submitted notes from Breakout group discussions

### Day One: MALS Draft Findings

**Substantive Findings on Local Knowledge Group**

1) *Need local knowledge to reveal information that is absent or invisible in Land Use and Land Cover Change (LUCC) maps* (given the type of maps we're using)

- Maps are good at showing the physical components of land cover change, but maps of land cover can miss important issues concerning the process of land use change.
- At Andrews locals perceive the change from working forest to retirement communities. We won't be able to interpret what is happening concerning LUCC unless big changes in clearing or bringing in tenure, i.e. public/private lands.
- At FCE, suburban areas may look identical in the maps, but LK reveals differences in underlying legacies of agricultural places as distinct from former marshlands. This correlates with differences in landscaping that are not visible from remote sensing/maps.

2) *LK Spatial Scale*

Local knowledge gives us the local scale/finer resolution (should we discuss the issue with maps here-not included in the data?)

At, Arctic sites: wildlife movements/fire/environmental change. At Coweeta and Harvard Forest: land use/management decisions. At CAP, implications of urban heat island driven by LUCC

3) *LK Temporal Scale*

We found that the issues and features associated with change as identified by local stakeholders were often different from those identified by LTER scientists. In particular, locals tended to identify rapid and visible changes (e.g., land use) more than slower, less visible changes (e.g., rising sea levels or temperatures).

Slower changes were identified by longer-time residents and resources users at some sites (e.g., vegetation change and shifting rainfall patterns among ranchers in southwestern deserts). Where climate change has occurred more rapidly, and locals have been present for longer time periods, the changes were identified by locals through indirect indicators (e.g, wildlife movement patterns or weather patterns among Eskimos in the Arctic).

We also found that the temporal depth of locals' observations could strongly affect their perceptions and knowledge of system attributes. For example, recently-arrived residents of housing built in the aftermath of Hurricane Andrew were relatively unaware of the risk of hurricanes to their neighborhoods. Long-time and more recently arrived residents in the HJ Andrews area had very different perceptions of what changes had occurred there, why, and with what consequences.

4) *Process, Patterns and Local Knowledge*.

LK helps to illuminate the process underlying the patterns. Explore the actual mechanisms. Can also help identify weaknesses in the data underlying maps. Structure and function (relate to ecological lit). This depends on what is mapped—fluxes can be mapped, it just doesn't happen very often. When and why these things happened?

*Climate Change Related Drivers*:

- At FCE, maps show demographic and development changes after Hurricane Andrew; LK reveals that this was a function of who had insurance.
- At CAP, had maps of vulnerability to urban heat island, and LK key to understanding how this came to be (e.g., policies about trees along irrigation canals)
- At JRN, fine scale vegetation change associated with water infrastructure. Underlying economic circumstances. Rationing and ag price supports WWI made money and then bought infrastructure.

*Development Related Drivers:*

- Real estate/development issue-mid-level theory/process, subdivision, suburbanization. CAP where/why development happened beyond simply demographic shift.
- Land cover maps may not reveal other changes, e.g., date of green-up or snow pack loss; wildlife migration routes or dates. LK can fill this in. ARC, BNZ, NWT
- Build environment shifts are better captured by the maps.
- FCE, CAP, Konza, PIE,

5) *Findings illuminated by New Methods for Spatial Analysis*

1. The process of land change in PIE has shifted from an early phase when developers were targeting forests to a subsequent phase where developers are avoiding forest.
2. The FCE site had 64 different categories, but our method of aggregation shows that it is possible to analyze the change by examining the behavior of only 12 categories.
3. Our cross-site analysis shows that PIE has a very consistent amount of change over time, while AND and JND have a relatively inconsistent amount of change over time.
4. CAP shows the epitome of a sprawling landscape where each pixel makes one permanent transition, whereas GCE is a landscape with much turnover where a single pixel experiences multiple transitions over time.
5. Error in the map of 1971 is unmeasured, but the commission error of forest in 1971 would need to be at least 14% in order for the error to explain the observed transitions from forest to built during 1971-1999.
6. In PIE, a linear extrapolation of land change cannot continue beyond 2036 because agriculture will disappear by then if present trends continue. It is impossible to compute a Markov matrix for GCE because the historic time interval is shows the emergence of a new category, i.e. Quarries.
7. In nearly all of the LTER sites, the locations of change during an earlier time interval tended to be the same locations that changed during a subsequent time interval, which directly contradicts an assumption of the Markov approach.
8. In PIE, early development tended to be concentrated on flat slopes, but now, new development is concentrated on steep slopes.

9. Two new measurements concerning the quantity and allocation of land categories is sufficient for all LTER sites, whereas the popular kappa index of agreement is not useful (Pontius and Millones 2011)

*Prospective Hypotheses/Emerging Questions*

- This comparative maps/LK has allowed us to identify key questions that we need to test.
- Lags: The temporal scale of feedbacks is critical to human responses to environmental change. Lags and inertia in feedbacks dampens human response.
- Coupling: More rural areas are more sensitive to local environmental changes due to greater degrees of coupledness.
- The less coupled sites are less vulnerable to local changes not because they are "decoupled" altogether, but because they are coupled to larger, extra-local ecological systems (for delivering water and food, for example). (good)
- The grain of landscapes becomes smaller as development (how are we defining this) progresses. Parcels become smaller, residents more numerous, habitats more fragmented, for example.
- Meanwhile, the extent of SESs expands as development progresses. Communities become linked to markets and other systems at great remove from their immediately experienced landscapes. This might be termed an increasing socio-ecological-spatial division of labor (including ecosystem functions as a kind of "natural labor.") At CAP, for example, farmers' adaptation to increasing drought has been limited due to policies and the extensive water infrastructure, which captures and transfers water from the entire Colorado basin.

**Collaborative and Cross-site Process Group**

- Meetings to build team cohesion and confidence in emerging leadership 'atmosphere things' – a climate that enables risk taking
  - Agree upon common terminology & definitions for key terms (for what phenomenon and what purpose)
  - Emergence of leadership and identification of champions
  - Compare methods and have a common framework emerge
  - Build trust/gain confidence
- Presentation of initial ideas
  - Professional meeting presentations reinforce the value of work based on instantaneous and interactive response from peers
  - Positive response from LTER Science Council further reinforced the value of work
  - All of the above provided confidence that the path forward was appropriate
  - And helped establish the MALS network of scholars
  - Talking about MALS helps other LTER scientists understand the value of the human dimension
- Sharing of existing literature that was relevant – team building: increased depth of scholarship

- Shared knowledge lead to more in-depth thinking
    - Site level knowledge sharing lead to meta-questions at the cross-site network level
    - Increase understanding of strength and weaknesses of the contribution of site-specific stakeholders
    - Realization of the diversity of approaches needed to deal with a diverse range of local conditions
    - Meta-question thinking enabled feedback to reassessment of site level : more in-depth thoughts/understandings
    - Assess the representativeness of local findings
    - Quick vetting of ideas and methods
- Learning from an interdisciplinary team: capitalizing on multiple perspectives
- Also people who have done team-work
- From site data/results to the meta analysis: creation of news theories/laws that can be generalized
- Understanding what you've got - increases the credibility of site specific results
- Contributes to breaking the disciplinary barriers: allows different researchers to see the role of different approaches in addressing big questions/issues
- Fitting the MALS idea into the ISSE framework
- Procedural fit: learn the mechanism of working into an pre-existing structure (the LTER Network) and getting new things to happen
- Better informs policy (relevance) and makes policy more credible locally

**Methods and Mapping Group**

Research efforts to-date emphasizing the comparative maps component of MALS have provided encouraging results and also raised concerns related to cross-site collaboration and idea synthesis. Individual LTER sites provided existing maps from varying dates and at varying spatial resolutions. The spatial analytical aspect of the project documented proof-of-concept as maps of change, rates of change, and spatially explicit information about the character of change were generated. Scholars from the varying LTER sites have examined the change maps and statistical output, gaining deeper insight into character of local system dynamics.

Research sites involved in the MALS effort represent a diverse collection of local areas that range from sparse desert environments to densely populated suburban locations. In order to make substantial progress rapidly, the land use/cover classes or categories were selected based on what was relevant for each site, rather than standardized across all the LTER sites. In addition, available imagery dates used to assess change and rates of change were obtained from existing local archives; again no attempt was made to standardize the pixel size (spatial scale of analysis) nor the dates used in the analysis (temporal scale). As such, the character of the information (while valuable at each specific site) did not lend itself well to cross-site comparison using conventional methods. Specifically, information about rates of land use/cover change could be calculated from a short time window at one location and from a much longer time window at a second location. In addition, analysis of changes provided using data a one meter resolution provides qualitatively and quantitatively different information than analysis done using maps derived from 30 meter Landsat sensor data. Thus, while the maps or spatial analytic component of MALS has been a success to-date, there are a number of issues with the current effort that could be improved upon with an expanded and better funded version of this project were to move forward.

## Day Two: MALS Draft Findings
## Full Group Discussion Notes – Synthesis and Hypothesis

*Towards integration and synthesis - maps and locals in a cross-site context*

- The wide heterogeneity of conditions at the 11 sites allowed our comparative analysis to span wide social and ecological gradients such as population, population density, land cover/land use, climatic and biotic circumstances, and rates of change in these factors.
- Comparison thus encompasses the full range of social-ecological systems present in the US, from wildland to rural to suburban and urban, arctic to subtropical. We found that change is happening at all our sites, often rapid change.
- We found that the issues and features associated with change as identified by local stakeholders were often different from those identified by LTER scientists. In particular, locals tended to identify rapid and visible changes (e.g., land use) more than slower, less visible changes (e.g., rising sea levels or temperatures). Slower changes were identified by longer-time residents and resources users at some sites (e.g., vegetation change and shifting rainfall patterns among ranchers in southwestern deserts). Where climate change has occurred more rapidly, and locals have been present for longer time periods, the changes were identified by locals through indirect indicators (e.g, wildlife movement patterns or weather patterns among Eskimos in the Arctic).
- We also found that the temporal depth of locals' observations could strongly affect their perceptions and knowledge of system attributes. For example, recently-arrived residents of housing built in the aftermath of Hurricane Andrew were relatively unaware of the risk of hurricanes to their neighborhoods. Long-time and more recently arrived residents in the HJ Andrews area had very different perceptions of what changes had occurred there, why, and with what consequences.

Findings such as these allowed us to generate a set of questions that were not readily apparent from individual sites taken alone. Over two years, through workshops and discussions, we began to generate cross-scale questions, some methodological and others substantive.

- LK may reveal patterns of change that are not revealed or are misrepresented in maps.
- Cross site mapping pointed to problems that led to innovation in new methods
    - Maps showed no assessment of accuracy; led to new method for accuracy assessment.

- What changes are reversible—or have “toggled” back and forth over time—and what changes are not?
- Is reversibility of change related to the rate at which change occurs? Are rapid changes more reversible, or less so?
- Is reversibility dependent on the persistence of local knowledge about prior conditions?
- How does length of time in a place affect the kinds of local knowledge that people have of that place?
- How does local knowledge spread, both among longer-term locals and from longer-term locals to newcomers?
- How local is “local”? In other words, does the spatial extent of a community’s self-definition change over time or across gradients? Local in sparsely populated areas may be quite large (e.g., ranchers in the southwest), but may be quite small in urban or suburban settings.
- How does local knowledge relate to “coupledness”?
- How should spatial analysis be integrated into the collection of local knowledge, and vice-versa? Can common methods be used across very different sites, or not?
- We found that different sites required different ways to integrate maps and locals
- More densely populated areas were more amenable to larger-scale approaches to local knowledge, with less direct collaboration in mapping. At PIE, for example, high-resolution satellite imagery was used to generate maps of neighborhoods, and these were linked to data from surveys regarding lawn management decisions. At , parcel data were collected separately from interviews with different categories of residents.
- In more sparsely populated areas and with longer-term, more coupled locals, mapping could be more collaborative and combined with more qualitative methods. Southwestern ranchers drew management practices on USGS quad maps of their ranches; arctic hunters drew migration patterns which scientists subsequently digitized. The information collected could also have greater historical depth, for obvious reasons.
- Where residents are more recently arrived, local experts could still be found, but their knowledge was likely to be pertinent to different kinds of processes. At CAP, for example, local knowledge was found among real estate developers and planning officials regarding suburban development.
- More rural areas are more sensitive to local environmental changes due to greater degrees of coupledness.
- The less coupled sites are the less vulnerable to local changes not because they are “decoupled” altogether, but because they are coupled to larger, extra-local ecological systems (for delivering water and food, for example).
- The grain of landscapes becomes smaller as development progresses. Parcels become smaller, residents more numerous, habitats more fragmented, for example.
- Meanwhile, the extent of SESs expands as development progresses. Communities become linked to markets and other systems at great remove from their immediately experienced landscapes. This might be termed an increasing socio-

ecological-spatial division of labor (including ecosystem functions as a kind of "natural labor."

- The temporal scale of feedbacks is critical to human responses to environmental change. Lags and inertia in feedbacks dampens human response.
- Broader implications
- Local knowledge helps us move beyond mechanistic approaches to SES. It mediates in both directions—from ecological to social systems and vice-versa—and it is inherently holistic. Locals are not "outside" the ecological system.
- Climate change dominates scientists' interest in SES; local knowledge tells us that there are other issues perceived to be more important.
- Including local knowledge entails building research partnerships, both for scientific purposes and to help ensure relevance

**Day Two: MALS Draft Findings**
**Common Research Questions and Protocols for**
**CHN Systems and other Proposals for Cross-site research**

- Questions:
    - How do climate change and Land Use/Land Cover Change (LULCC) interact with local processes and local agents, including down scale and upscale feedbacks?
    - What do locals know about these changes, and how does their knowledge affect their actions and the resulting outcomes?
    - How does this knowledge interact with, compare to, and inform understanding through mapping?
    - What do locals want to see happen in their landscapes and communities, and how can SES research contribute to realizing their objectives?
- Methods for Research at Individual LTER sites
    - Identification of key livelihood activities/economies
        - What are current and past dependencies and feedbacks with local ecological systems
        - Basic history of local economic systems: how long in place, what preceded, key periods of change, affects on community size and composition - This could be glossed as filling in one of the boxes already present in the ISSE conceptual diagram
        - Basic history of landscape changes and legacies - This could be glossed as filling in one of the boxes already present in the ISSE conceptual diagram
    - Assessment of "locals" and sources of expertise
        - Residents/users of longest duration/tenure
        - Recognized experts within key subcommunities
        - Academic/scholarly experts (e.g., environmental historians)
        - Archival information (e.g., local newspapers)
    - Refine, improve, and/or augment spatial analysis of land cover change over time

    - Iterative, flexible use of spatial analysis and LK methods
        - May make maps first, then take them to locals for their feedback and input
        - May make maps with locals first, asking them to draw/provide the maps and identify key features and changes over time
        - May go back and forth doing both, revising the maps in dialogue with locals
        - Choice of LK collection methods tailored to the contexts of the sites and to the questions being asked
            - In large, recently-arrived populations, quantitative methods such as surveys and questionnaires may be appropriate
            - Qualitative methods will be necessary, though they will vary with the context
                1. Ethnographies/participant observation
                2. Local or oral histories
                3. Semi-structured interviews with key "experts"
                4. Participatory mapping
            - Questions being asked may come from the scientists, the locals, or both in communication with each other
- Methods for Cross-site comparison
    - PIs with grad students/post-docs at each site focused on the effort at that site, collaborating with GIS/spatial analysis experts
    - Grad students/post-docs meet regularly and work together on cross-site coordination and comparison
    - Array sites along gradients
        - Length of residence of locals (average and range)
        - Coupledness of local economic and ecological systems: how much do locals depend on their local system for their livelihood?
        - Degree of land cover modification by people: percent of area built up, cultivated, otherwise altered
        - Rates of change in land cover: fast/slow, recent/old, accelerating/decelerating
    - Group sites according to common positions along gradients, understanding that this may result in several, differently overlapping categorizations (or combinations of positions/attributes)
    - Formulate common questions and methods for each group of sites
    - Form sub-teams of grad students/post-docs that work collectively across their sites
    - Invite locals from each site to participate in the sub-teams as collaborators
    - Work with GIS researchers to integrate LK into spatial databases
    - Work with local groups and agencies to use resulting knowledge for restoration, management, monitoring, planning or adaptation projects
    - Educational component: workshops, school groups, interactive online tools, curriculum development, presentations, partnerships with local educational providers

### Appendix 4: DRAFT paper on MALS results to date

## Maps and Locals (MALS): An experiment in integrating spatial analysis and local knowledge across LTER sites to study the dynamics of social-ecological systems

Objective: Assess the potential of the LTER network to do cross-site, transdisciplinary research about SES

Thesis: The integration of Maps and LK in cross-site LTER research in the study of SES dynamics offers important benefits with significant challenges. By combining GIS-based spatial analysis, qualitative local knowledge collection, and cross-site comparison, we have developed new methods, new questions, and a new framework for future studies.


### Abstract

Understanding the dynamics of social-ecological interactions and organizing system-wide investigations through comparative analysis of LTER sites are key objectives of the NSF-LTER's Integrative Science for Society and Environment (ISSE) Decadal Plan. These objectives address a grand challenge for both applied and theoretical ecology: to discern past human effects on ecological systems and distinguish anthropogenic from non-anthropogenic drivers of change. Although most LTER sites have assembled historical data on land cover, climate, vegetation, and other ecological attributes, less is known about the legacies of historical resource management practices and other human influences. In many cases such data are available for human communities of LTER regions, but are not well compiled. Local knowledge (LK) from residents and users of landscapes provides an additional source of insight with potential to add to LTER studies, but methods for documenting and integrating such data into ecological research remain poorly developed and a subject of debate. Our objective in the Maps and Locals Project (MALS) was to develop methods and capacity for research into social-ecological systems both at individual sites and at the network scale.


### Introduction

This paper presents the efforts and outcomes of Maps and Locals (MALS), a cross-site Long-Term Ecological Research (LTER) network project undertaken in 2009-2011 to utilize both local knowledge (LK) and spatial analysis to understand the drivers, issues, and dynamics of land use and land cover change (LULCC). MALS follows from and adds to the recent movement to develop and make operational the Integrative Science for Society and Environment (ISSE) initiative, which seeks to integrate social science into the LTER network by approaching LTER sites as coupled social-ecological systems (SES). The ISSE broadens the established ecological focus of LTER studies by expressly including human dimensions, on the premise that humans and environments are inextricably linked. MALS extends this enterprise by (1) incorporating LK as a critical component of SES; (2) examining both past and present human influences on LTER sites; and (3) comparing SES dynamics across multiple sites that span wide biophysical and social gradients. In addition to substantive findings, MALS reveals epistemological and methodological challenges and opportunities in expanding the LTER program to include social science.

MALS was motivated by rapid global scale change, evidenced by significant land cover and land use changes at regional and local scales, and by a growing recognition among researchers, resource management professionals, and other stakeholders that mixed methods of research, drawing on multiples ways of knowing, can contribute to the work of science in meaningful and highly constructive ways and can make scientific research more policy relevant. The central organizing question of MALS is how global climate change and other large-scale anthropogenic forces (e.g., globalization) are manifest as local land use and land cover change, interacting with local processes and agents through downscale and upscale feedbacks. MALS represents an experiment designed to assess the potential of the LTER network to do SES research that integrates qualitative methods of LK collection with quantitative spatial analysis.

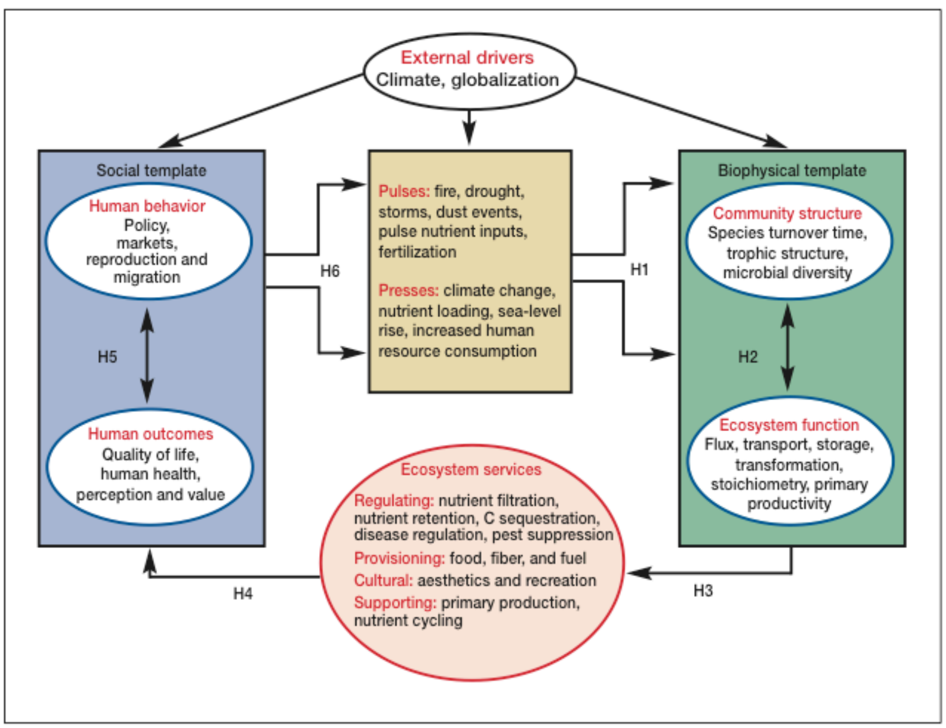



Figure X: ISSE conceptual framework of social-ecological systems (SES) (Collins et al. 2010).

Local knowledge has often been conceptualized as opposed to scientific, experimental knowledge, and considerable debate has ensued as to whether LK is accurate or reliable enough to be deemed “scientific.” As demonstrated by our experience, we argue here that these two kinds of knowledge, while different, are best approached as complementary (rather than competitive) and that the study of LULCC can benefit from combining them. Here we provide background on our approach, describe the efforts and findings of MALS, and present a general framework for the integration of LK and spatial analysis in the context of long-term ecological studies across diverse sites of the United States.

## Background on LULCC and LK studies

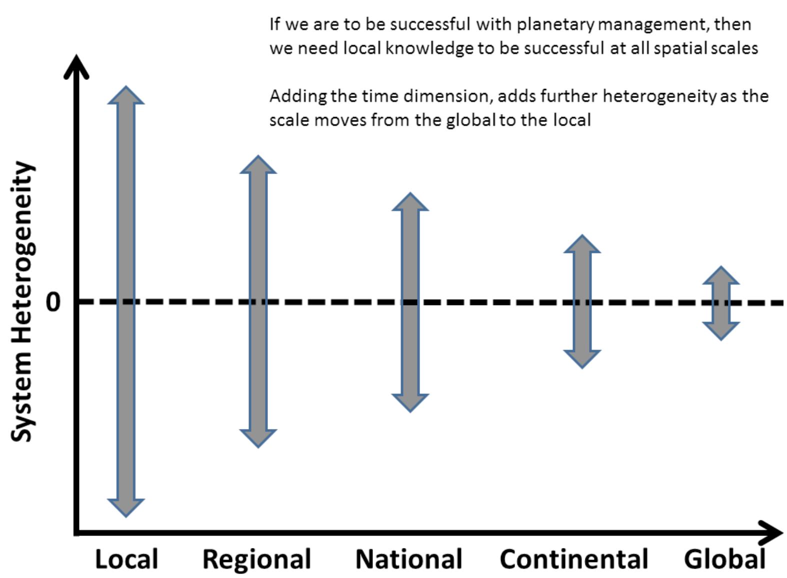
The theoretical grounding of MALS begins by adopting a coupled social-ecological systems (SES) approach to understanding the structure and functioning of ecosystems. Building on the ISSE's core contention that SES should be incorporated with Long-Term Ecological Research, we make the case that LK should be incorporated into the study of SES. As understanding of the functioning of ecosystems has progressed both locally and globally, it has become increasingly clear that humans are a major driver of system change (Vitousek et al. 1997) and that the unprecedented growth in human population, related resource consumption, and their combined effects on the Earth system since the Industrial Revolution indicate the advent of the Anthropocene, a new geologic era (2000). This idea suggests a transformation to an unprecedented or no-analog system characterized by planetary-scale domestication of nature (2007), the dominance of anthropogenic biomes (2008), and the probability of future tipping points (2009). If humans are to do an acceptable job of managing the Earth system, we need to be aware of variations in system functioning at a range of spatial and temporal scales. In this context, past approaches of single disciplinary, reductionist science are inadequate to advance understanding of change.

One approach to enable a more holistic perspective of human impacts on the planet is to study how human actions have altered surface cover. Land change science (Turner et al. 2007) has emerged as a multi-disciplinary scholarly approach to gain knowledge about system change. By combining perspectives that include spatial analysis and geographic information systems (GIS) with maps and/or images of the surface and with social science perspectives on the drivers of system change, land change science provides unique insights. Whether the initial imagery comes from a camera or a satellite sensor system, remote sensing techniques can be used to provide a transformed product in a map format with specific information categories interpreted from the initial data. Comparison of multiple maps prepared using similar procedures and information categories allows analysis to obtain spatially explicit information about locations, types and rates of LULCC.

Land change science research efforts have helped tease out the variations from place to place in important drivers of landscape change (Lambin et al. 2000). Synthesis efforts for various biomes have led to an improved understanding of the distinction between proximate causes (e.g., the expansion of a road network) and underlying drivers (e.g., demographics, economics, culture) of change (Geist and Lambin 2002, 2004). Foley et al. (2005) aggregated land change information at the global scale and raised concerns about changes in ecosystem services delivery. They suggest that "developing and implementing regional land-use strategies that recognize both short-term and long-term needs, balance a full portfolio of ecosystem services, and increase the resilience of managed landscapes will require much more cross-disciplinary research on human-dominated ecosystems."

Wilbanks and Kates (1999) showed that there is considerable value in understanding system functioning at scales from the global to the local, rather than assuming linear relationships among them. They argued that "central relationships underlying global change are too intractable, too complex, to trace at any scale beyond the local," and that "differences in perspectives between 'macro' and 'micro' provide many examples of situations where researchers looking at an issue top-down come to different conclusions from those looking at the issue bottom-up." As the scale of observation moves from the global to the local, the degree of system heterogeneity increases (Figure 1). Adding a historical dimension to system understanding increases the level of heterogeneity further, and at all scales. This heterogeneity suggests the need to account for local level processes more carefully.

Anthropologists and other social scienists have long understood the value of local people's knowledge in understanding patterns and mechanisms of social-ecological conditions and dynamics. Local knowledge has been used to understand cultural traditions, resource management practices, historical perspectives on ecological change, and to address the problem of scale. Early work strongly dichotomized local and scientific knowledge, with lasting effects on subsequent scholarly debates. For example, anthropologist Claude Levi-Strauss (1962) argued that there are two parallel modes of acquiring knowledge about the universe, fundamentally distinct in that "the physical world is approached from opposite ends in the two cases: one is supremely concrete, the other supremely abstract." Other distinctions have also been highlighted, including the close connection between LK and practices situated in specific times and places, as contrasted to the generalizing objectives of science. A great deal of effort has been expended in either defending or assailing the accuracy and reliability of LK as compared to knowledge produced through scientific experimentation and hypothetico-deductive reasoning.



In this paper we follow Berkes and others in defining LK as an interacting system of individually and collectively held observations, theories, and preferences about a place, organized into an ideology (in a non-pejorative sense). Local knowledge encompasses both traditional ecological knowledge (TEK), which scholars have generally associated with indigenous peoples, and local ecological knowledge (LEK), which may be held by indigenous or non-indigenous groups. Because of the variety of sites in our study, we do not limit LK to ecological topics, conventionally defined, but instead include any knowledge relevant to processes of landscape change in a place. We recognize that LK can accumulate through time and across generations; that it may entail distinct modes of learning and thought produced through intimate relations with land and resources; and that LK is central to many time-tested strategies of human survival in diverse environments.

We see local knowledge and scientific knowledge not as opposed but as different and in most cases complementary. We do not seek to evaluate one against the other or measure their value against some singular standard, but rather to use each to help identify and fill gaps, generate hypotheses, and illuminate the interaction of social and ecological processes at multiple scales and across scales. For example, recent work in land change science reveals that no single driver can account for patterns of desertification and deforestation globally; rather, suites of drivers interact in locally and regionally specific ways. Similar patterns of land cover change at different places do not necessarily mean similarity in mechanisms and drivers. Local information must be collected to enable these variations to be understood. Local knowledge can also address limitations in data derived from other sources. For example, quantitative social scientific data—such as demographic and economic information available from the Census—are abundant and have been used to study land cover change in the US at county resolution (USGS). Quantitative approaches can reveal patterns in SES observable at various scales. However, qualitative methods are needed to identify the mechanisms underlying these patterns (Sayer, others). Local knowledge is an important source of such qualitative data.

## MALS objectives and process

**MALs** involved a cross-site collaborative effort with complementary areas of activity. Participating LTER sites (1) used spatial representation of land cover and land use to identify patterns of landscape change in regions in and around LTER sites; (2) documented and integrated LK and other existing social data into theories and models of ecological change to understand implications for human livelihoods; and (3) participated in an iterative effort to integrate the two resulting bodies of data and interpret them through cross-site comparison. The first component was methodologically standardized across all sites, although there was wide variation in the scales and categories of the maps available. The methods and details of the second component varied widely among sites. The third, integration and cross-site comparison, aided in developing methods and questions, in testing hypotheses over larger scales, and in setting the stage for future cross-site comparative studies.

The MALS project was launched in response to a call for coordinated proposals to the NSF LTER Social Science Supplement funding program, which offered $20,000 per participating site. The organization of the project included an altruistic element by asking each site to forgo a portion of its funding and contribute it to a collective effort at spatial analysis. Much to the surprise of the organizers (Kofinas, Pontius, and Sayre), 11 LTER sites applied and were funded to participate in the first phase of the study. Interactions of site investigators occurred at several venues, initiated with a workshop at the September 2009 All Scientists Meeting of the LTER Network in Estes Park, Colorado. This was followed by a series of virtual meetings to evaluate and define problems of LULCC across sites, and to develop methods and strategies of integrating LK research. A key focus was identifying social and ecological processes that are hypothesized to drive SES change in the regions in question, and attempting to specify the spatial and temporal scales of those processes. The findings of MALS's spatial analysis were presented as posters at the annual meeting of the Association of American Geographers (AAG) in Washington DC in April 2010. A second face-to-face workshop took place in Fairbanks, Alaska, in October 2010, where site researchers shared LK results and began grappling with cross-site questions. Ten LTER sites secured a second year of Social Science Supplemental funding for 2010-2011, contributing a portion of their site's supplement to a common effort to synthesize LK research across sites. Further face-to-face interactions occurred in a panel discussion at the AAG meeting in Seattle in March 2011, in which a more synthetic exploration of ideas and directions was articulated, and at a workshop at the HJ Andrews Experimental Forest in Oregon in June 2011, where the group developed a common framework and directions for future studies.

The three major elements of MALS were (1) mapping and spatial analysis; (2) local knowledge collection; and (3) integration and cross-site comparison. For all three, we found that methodologies had to be developed and significant data quality issues overcome, with the result that our findings are as much methodological as substantive in nature.

*Mapping:* Each site assembled a time series ($n>2$) set of maps that represent known biophysical, infrastructural, and/or land-use changes in its region. Each set of maps showed two or more land categories overlaid on a single raster grid to facilitate statistical analysis. In theory, this would allow analysis of whether processes of land transformation had been continuous across multiple time intervals (which we termed "stationarity") or had varied in rates, locations, or directions from one interval to the next. The need to develop a comparable method of spatial analysis for a wide variety of sites, with different land type categories, revealed numerous challenges in both data quality and methods. At each site, maps were used as corroborating data and in some cases as research tools for use in collecting LK.

*Local Knowledge Documentation and Social Data Collection:* For the documentation of local knowledge, we identified individuals and classes of informants at each site, with an emphasis on people who have had continuous or regular familiarity with specific places over long time periods (10-50 years, or potentially more through ancestors). This familiarity involved direct management of a property or repeated regular visits for specific purposes. Considerable information about local knowledge had already been documented at some sites through past and current research projects, and to the extent possible, these data were incorporated into the project. Additional new data were collected where opportunities and resources were present.

*Coordination and approach:* We sought a Linux-like, open-source organizational approach to our collaboration and intentionally left many of our specific activities and research questions loosely defined at first, pending further refinement over the course of the project. Table 1 summarizes the postulated critical drivers of change at each site and the kinds of spatial analysis and LK studies conducted.

| LTER site | Critical driver(s) | Spatial analysis | Social Science/ Local Knowledge |
|---|---|---|---|
| **Andrews (AND)** | Post logging restructuring of system | Land use mapping | Interviews with "old timers"; survey research; institutional analysis |
| **Arctic (ARC)** | Oil development and climate change | Historic land cover maps from oil industry | Interviews with locals (including oil field workers) on changing subsistence resource availability |
| **Bonanza Creek / Interior Alaska (BNZ)** | Climate change; increased fire frequency | Retrospective and prospective maps generated by model | Group interviews with indigenous harvesters |
| **Central Arizona-Phoenix (CAP)** | Urban sprawl and climate change | Fragmentation; land use change | Institutional research; environmental justice, risk and vulnerability; comparative urban research |
| **Coweeta (CWT)** | Density change, demographic change | Multiple methods of analysis (view sheds, watersheds, participatory mapping) | Individual choice; documenting local knowledge of historic change; perceptions of change in "small town" character |
| **Florida Coastal Everglades (FCE)** | Land conversion, water budgets | Historic cadastral mapping | Ethnographic analysis and other forms of social science |
| **Georgia Coastal Ecosystems (GCE)** | Land use and water level changes in estuary and marine ecosystem dynamics | Use of SLAMM (Sea level affects marshes model) with other tools | Limited to no social science involvement |
| **Jornada Basin (JRN)** | Vegetation; land use change; grazing legacies | Maps with repeat photography | Ranchers' knowledge of change tied to changes in land-use practices. |
| **Plum Island Ecosystems (PIE)** | Increases in density and type of residential uses | Density mapping; | Group truthing with visual verification and GPS field work |

| | | | |
|---|---|---|---|
| **Konza Prairie (KNZ)** | Land use change, woody invasions; exurbanization and loss of traditional ranching and agriculture | Multiple spatial analyses of agrarian transition | Semi-structured interviews of farmers & ranchers and other local specialists |
| **Niwot (NWT)** | Woody encroachment; mountain pine beetle outbreak; changes in snowpack and runoff | Acquisition and orthorectification of aerial photos; land cover maps | Analysis of socio-economic data |

## Findings

Although a few sites already had social scientists on their research teams, including ARC and BNZ and several located in urban or suburban settings (CAP, PIE, and FCE), most sites had very limited pre-existing capacity to undertake the MALS research. Some had no social scientists involved at all; others had done social scientific research but only of a quantitative nature not well suited to LK collection and analysis. Existing GIS and spatial analysis capacity was also uneven and quite limited at some sites. Although the per-site funding made available through MALS was not sufficient to hire full-time personnel, many sites reported that MALS enabled them to initiate studies that otherwise would not have been possible, and that the MALS funding helped to leverage other resources.

Substantial methodological challenges also confronted MALS in all of its components. New methods were needed for spatial analysis both within and across sites. The wide diversity of conditions across sites necessitated flexibility in the methods used to identify, collect, and interpret LK data. In some cases it proved useful to use the maps from the spatial analysis component in collecting LK, but not in others. This methodological diversity raised new questions and hypotheses when we situated our results in comparative context.

Overall, we found that understanding processes and mechanisms of LULCC required cross-scale, interdisciplinary contributions, and that LK was critical to capturing the complexity of SES. More specifically, qualitative methods were necessary both for the collection of LK and the interpretation of changes documented by mapping and spatial analysis. The fact that many methodological challenges and shortcomings in available data were common across all our sites made it easier to discuss these problems and collectively develop suitable responses, confirming the value of a collaborative research process with a significant community element. Our findings, then, are of two sorts: first, the challenges we encountered in each of the three project components—mapping, LK, and integration/cross-site comparison—and how we responded to them; and second, a summary of substantive results, offered as emergent common themes and hypotheses for further research.

Findings regarding data and methods

*Mapping and spatial analysis*

The maps component of MALS has provided encouraging results and also raised concerns related to cross-site comparison and idea synthesis. The spatial analytical aspect of the project documented proof-of-concept as maps of change, rates of change, and spatially explicit information about the character of change were generated. Scholars from the varying LTER sites have examined the change maps and statistical output, gaining deeper insight into character of local system dynamics.

Individual LTER sites provided existing maps from varying dates and at varying spatial resolutions. In order to make substantial progress rapidly, the land use/cover classes or categories were selected based on what was relevant and available for each site, rather than standardized across all the LTER sites. In addition, available imagery dates used to assess change and rates of change were obtained from existing local archives; no attempt was made to standardize the pixel size (spatial scale of analysis) nor the dates used in the analysis (temporal scale).

Most sites already had some maps or the raw materials to produce them. However, these data were incomplete and/or in need of better documentation. A common trait of maps from all sites was the absence of metadata necessary for assessing quality, which was especially problematic for comparing maps across time. For example, the BES site had a potential gold mine of JPG files that showed urban expansion for fourteen non-consecutive years extending back to 1792. Without metadata, however, it was impossible to reconstruct the precise meaning of "urban," which made it difficult to interpret apparent anomalies such as why a substantial piece of Baltimore City lost urban land cover between 1925 and 1938. Maps had been made at different scales and by different methods, utilized different categories, and/or covered non-identical areas. Cross-tabulation matrices were unavailable. Furthermore, it was not clear how to select the bounding coordinates of the study extent for the raster grid, since many existing maps were in vector format and many of the variables had different spatial extents.

We concluded that the existing maps would have to be substantially revised or replaced with newly created maps in order to make precise estimates concerning land change. This would entail very labor-intensive digitizing of paper maps and aerial photographs. Even if we had those labor-resources, the map comparison over time would encounter some substantial conceptual and methodological hurdles regardless of the accuracy of the data. Therefore, we have designed new methods to deal with the general challenges in the analysis of land change using maps from multiple points in time. (Table 2).

Table 2: New methods that were developed to address spatial analysis needs of MALS.

| |
|---|
| To measure the stability of land transitions over time |
| To aggregate categories strategically to form a small number of important categories |

| |
|---|
| To compare various sites concerning the stability of land transitions |
| To distinguish between sprawl change and turnover change |
| To quantify the amount of error that could explain the differences in maps |
| To extrapolate categorical transitions over time |
| To test whether changes tend to occur at the same places in consecutive time intervals |
| To show graphically the comparison between a rank map and a Boolean map |
| To kill the popular Kappa statistic |

For example, in some cases it was not clear how best to define land categories. The CAP site had some maps with 21 categories and others with only 4. We therefore developed a methodology to reduce the number of categories, since 21 categories can produce a dizzying array of more than 400 possible transitions, while the use of only 4 categories might mask some important transitions. How best to aggregate categories had been addressed by Pontius and Malizia (2004), who distilled the mathematical principles that dictate how category aggregation influences measurements of land change over time. Furthermore, we found some substantial erroneous artifacts in some of the LTER sites' maps, such as seams in the elevation maps, which are not immediately evident until we used the elevation map to create a slope map. In the absence of metadata concerning the accuracy of maps, we used the methods of Pontius and Lippitt (2006) to examine how the suspected errors in the maps influence the estimates of land transformation.

We tested the hypothesis that recently proposed methods would be particularly well suited for this type of cross site comparison. Pontius et al. (2004) proposed a novel method to test for systematic transitions among land cover categories when maps are available from two points in time. Their methods revealed that new expansion of built land in Massachusetts targets open space and avoids forest, in spite of the fact that most of the gross gain in built displaces forest. The reason is that the initial landscape is mostly forest, so the gain of the built environment is likely to displace forest even when developers prefer to avoid deforestation. Alo and Pontius (2008) advanced this method in order to compare two different sites to test whether the processes of land transformation inside a protected area are different from the processes outside a protected area. MALS advanced this methodological approach by examining the transitions among maps from three points in time to determine whether the transitions during the former time interval are different than the transitions during the latter time interval. Chen and Pontius (2010) have proposed a complementary method to test whether the process of land transformation is stationary along a gradient, e.g., slope or distance to forms of human infrastructure such as highways.

*Local Knowledge*

A variety of methods are available from the social sciences for documenting LK, including ethnography, participant-observation, interviews (structured, semi-structured, and open-ended), oral histories, focus groups, surveys and questionnaires, and archival research. No single common method was used across our sites, due to the great diversity of communities, issues, and questions being addressed.

Local knowledge collection fell into two broad types across sites. First, several sites sought LK of a historical nature, looking backwards in time and asking questions about when and why certain known changes in land use and land cover had occurred. In these cases of *long-term ecological knowledge*, questions generally originated from scientific, ecological concerns represented in the maps, and sources of LK were long-time residents or users of specific landscapes and resources (e.g., indigenous peoples' knowledge of caribou migration patterns in Alaska, ranchers' knowledge of fine-scale vegetation changes in the Southwest, or farmers' knowledge of land use change in the suburban edges of Miami). The maps themselves could serve as a prompt in collecting LK at these sites (such as at AND), but in some cases this was deemed inappropriate for cultural reasons (ARC and BNZ) or because locals had their own maps and voluntarily used them to document and explain change (JRN). Either way, methods of LK collection were highly qualitative and utilized non-random methods of selecting locals to interview.

Second, many sites sought LK related to recent and ongoing processes of change, asking how present residents and users perceive, evaluate, and interact with their landscapes. Examples included how landowners make decisions about harvesting timber or conserving forests in HRV and HBR; how locals value open space or other landscape attributes in NWT, FCE and NTL; how low-income residents experience and respond to the urban heat island effect in CAP; how residents make decisions about lawn and yard management at PIE; and how people perceive changes in ecosystem services at KNZ and NTL. In these cases, mapping and spatial analysis generally served as a means of identifying who to seek out for LK collection, for example by revealing individual parcels or neighborhoods where the spatial data indicated important or measurable changes had occurred. The duration of residence or use did not need to be long and was often quite short (e.g., in recently developed suburban areas), sampling could be random or otherwise non-selective, and methods of LK collection could be quantitative or quantifiable (e.g., mail surveys or questionnaires).

These contrasts suggest a number of important considerations for LK collection at LTER sites. Who is (or counts as) "local" varies widely and affects the kinds of data that can be collected and how to collect it properly. Long-time residents or "oldtimers" may not be available; they may have moved away and no longer be on-site. In some locations, absentee landowners may represent a significant portion of the "local" population in terms of land use and land cover decision-making, but reside in other places altogether. Recently arrived residents may have little in the way of "local" knowledge of their landscapes, but instead bring knowledge from other sources and sites to bear on their new places; the category "newcomer ecological knowledge" or NEK was developed at AND to help identify and conceptualize this phenomenon. Finally, diagnostics for assessing LK data quality are needed, especially where samples of locals are small and/or non-random.

*Integration and cross-site comparison*

Research sites involved in the MALS effort represent a diverse collection of local areas that range from sparse desert and arctic environments to densely populated urban and suburban locations. Both the maps and the LK varied considerably across sites in terms of scales, methods, and underlying data quality. As a result, the character of the information, while valuable at each individual site, did not lend itself well to cross-site comparison. For example, rates of LULCC were calculated over shorter time windows at some sites and over much longer windows at others. The results could be standardized into units of change per year, but the kinds of information thus summarized—and the questions remaining to be answered—were very different across sites. In addition, analysis of changes using data at one-meter resolution provided qualitatively and quantitatively different information from analysis done using maps derived from 30 meter Landsat sensor data. Similar methodological issues arose in relation to cross-site comparison of LK data. Interestingly, however, the two kinds of information—maps and LK—and the two scales of analysis—individual sites and across sites—proved to be complementary when utilized together iteratively. Each helped in evaluating the others, revealing and in some cases filling in gaps, illuminating common problems and suggesting potential solutions.

The degree of integration of maps and LK varied between sites, although in all cases researchers used both together in one fashion or another. We found that different sites required different ways to integrate maps and locals. More densely populated areas were more amenable to larger-scale approaches to LK, with less direct collaboration in mapping. At PIE, for example, high-resolution satellite imagery was used to generate maps of neighborhoods, and these were linked to data from surveys regarding lawn management decisions. At FCE, parcel data were collected and mapped separately from interviews; the maps helped to identify the different types of residents to be interviewed. In more sparsely populated areas and with longer-term locals, mapping could be more collaborative and combined with more qualitative methods. Southwestern ranchers drew management practices on USGS quad maps of their ranches; arctic hunters drew migration patterns which scientists subsequently digitized. The information collected could also have greater historical depth, for obvious reasons. Where residents were more recently arrived, local experts could still be found, but their knowledge was likely to be pertinent to different kinds of processes. At CAP, for example, local knowledge was found among real estate developers and planning officials regarding suburban development.

Generally speaking, the maps (and the spatial analyses derived from them) seemed poorly suited to the perspectives and concerns of locals. In AND, where the maps were used as prompts in interviews with local residents, many oldtimers objected to one of the mapping categories, "clear cut," insisting that the term "managed forest" would be more appropriate because clear cutting of trees is standard, accepted management practice in the region's timber industry. This may have impeded LK collection by making some locals defensive or suspicious of the research, and suggests the need for developing map categories with local input and/or sensitivity to local terminology and perspectives. Many maps were so full of details as to be difficult to interpret, especially when accompanied by complicated tables and graphs depicting the results of spatial analyses.

The temporal and spatial scales of the maps were often mismatched to the scales of LK. In most of these cases, the map scales were too coarse, and/or the extents too large, to capture the features of most interest to locals. Especially where locals had arrived in the region recently, they struggled to find resonance with maps depicting much longer-term patterns of change, and they tended to describe local landscape changes at very fine scales of space and time: what they had observed in their own experience and at specific, meaningful locales such as their own properties or neighborhoods. The one exception was at JRN, where longtime ranchers were invited to develop or annotate maps of their own properties, meaning that the scales of the maps and the LK were aligned by design.

These mismatches were in many ways a strength, however, as LK helped to interpret, at finer scales, the coarser patterns found in the maps. At FCE, for example, locals pointed out differences in the tree species found on suburban properties that had formerly been farms, as compared to those on former marshland. Such legacies were not captured on the maps, which had been developed from remote sensing imagery. Local knowledge at BNZ and ARC was finer in scale than the maps and helped identify locally important ecological phenomena concerning resource availability. At CWT and HRV, LK revealed the fine-scale patterns of land use and land management decision-making (whether to harvest timber, and if not, whether to impose conservation measures) not apparent in the maps. And at CAP, LK illuminated fine-scale land cover changes such as tree removal along irrigation canals, whose contribution to urban heat islands had eluded researchers previously. Finally, in several cases, maps were too coarse categorically, lumping together under one land use category (e.g., residential) locally important distinctions (e.g., timber industry households vs. retiree or second home households) due to commonalities of the associated land cover.

### Substantive Findings

Because of the issues of data quality, cross-site comparability, and methodological diversity already described, many of our findings take the form of emergent common themes and hypotheses for further research, rather than firm conclusions. The wide heterogeneity of conditions at the 11 participating LTER sites entailed a comparative analysis that spanned extreme social and ecological gradients such as population, population density, land cover/land use, climatic and biotic circumstances, and rates of change in these factors. Encompassing such a wide range of SES, from wildland to rural to suburban and urban, arctic to subtropical, is unusual for studies involving LK and qualitative methods. By forcing us to compare such diverse sites, MALS provoked new ideas and questions in addition to new methodologies.

*Emergent themes*

Cross-site comparison of maps and LK strongly suggested that the two kinds of information are complementary in terms of spatial scale. Local knowledge generally captures a finer resolution of information about landscape changes than maps derived from "top-down" sources such as satellites and databases can capture. Local knowledge at CAP, for example, provided insights into processes of subdivision and suburbanization at neighborhood and municipal scales, explaining where and why development happened at a resolution that demographic and land cover data could not reveal. It is possible that higher resolution mapping technologies might eventually reduce this disparity, but related issues of categorization and typologies would remain.

Similar lessons can be drawn regarding the temporal scales of maps and LK. We found that the issues and features associated with change as identified by local stakeholders were often different from those identified by LTER scientists. In particular, locals tended to identify rapid and visible changes (e.g., land use) more than slower, less visible changes (e.g., rising sea levels or temperatures). Slower changes were identified by longer-time residents and resources users at some sites (e.g., vegetation change and shifting rainfall patterns among ranchers in JRN). Where climate change has occurred more rapidly, and locals have been present for longer time periods, the changes were identified by locals through indirect indicators (e.g, wildlife movement patterns or weather patterns among Eskimos in the Arctic).

We also found that the temporal depth of locals' observations could strongly affect their perceptions and knowledge of system attributes. At FCE, for example, recently arrived residents of housing built in the aftermath of Hurricane Andrew were relatively unaware of the risk of hurricanes to their neighborhoods. Long-time and more recently arrived residents in the AND area had very different perceptions of what changes had occurred there, why, and with what consequences.

In general, LK complements knowledge from maps by helping to illuminate the processes underlying spatial patterns. Not only could ranchers at JRN specify dates of vegetation change more precisely than available maps could; they could also explain that fine scale vegetation changes were related to investments in water infrastructure, for example (which enabled livestock grazing in previously unwatered areas), and that these were in turn made possible by periods of high cattle prices and government policies that gave their predecessors the financial resources to make such investments. At FCE, maps could show demographic and development changes after Hurricane Andrew; LK revealed that this was a function of which homeowners had insurance. And at CAP, maps revealed patterns of vulnerability to urban heat island effects, but LK was needed to understand how this came to be (e.g., policy and management changes about trees along irrigation canals). In summary, LK reveals mechanisms of change that spatial analysis generally does not capture. It can also help identify weaknesses in the data underlying maps.

Stated in ecological terms, we found that while our maps depicted structural aspects of SES, LK captured SES function. It should be noted that this formulation is a heuristic analogy, and that it depends on the kinds of maps being used. Maps of land use and land cover depict state conditions; other types of maps—of fluxes, for example—might disrupt this analogy. But such maps are relatively uncommon, and might still require other types of knowledge to explain when and how the patterns depicted were produced. Other limitations in land cover maps can also be overcome through LK collection. Locals at ARC, BNZ, or NWT pointed out some important changes have occurred—in the date of migrations, green-up, or snow pack melt, for example—even where mapped land cover remained unchanged.

### *A framework and hypotheses for future research*

Building on the ISSE framework of coupled social and ecological systems, and on the contention that LK influences LULCC by shaping both how biophysical changes are perceived and how people respond to them, we propose a focus on the linkages and feedbacks between LULCC and LK over multiple scales of space and time. We identified several dimensions on which to situate our sites for comparison:

1) Degree or scale of 'coupledness' of the local SES: how much local people depend on their local landscape and its ecological services for their livelihoods (as compared to importing goods and services from remote/larger systems)
2) Intensity of the built environment: how much (percent of area) of the local landscape has been modified by human activities, and in what ways (e.g., crops, impermeable surfaces—note that "built" is not limited to *buildings* or *construction* but also includes plowing, planting, cropping, etc.)
3) Duration of residence or tenure in the landscape by present inhabitants or users: how long (mean and range) current people have been in (or using) a given place

These comparative dimensions, and our research findings, allowed us to formulate the following hypotheses for future study:

i) Lags or inertia in feedbacks from biophysical to social systems dampen human responses; slow variables or 'press' disturbances are less likely to prompt concerted, intentional reactions than fast variables or 'pulse' disturbances
ii) Places with lesser intensities of built environment are more sensitive to local environmental changes due to greater degrees (smaller scales) of coupledness; they are also more vulnerable to external drivers (understood as originating outside of the SES under study—see Figure 1), such as climate change and globalization

iii) Less coupled sites are less vulnerable to local changes not because they are "decoupled" altogether, but because they are coupled to larger, extra-local ecological systems (for delivering water and food, for example)
iv) The grain of landscapes becomes smaller as the built environment intensifies; parcels become smaller and more numerous, habitats/landscapes become more fragmented, etc.
v) Meanwhile, the extent of a SES expands as the built environment intensifies; communities become linked to markets and other systems at great remove from their immediately experienced landscapes through transportation, communication, etc. (this might be termed an increasing socio-ecological-spatial division of labor including ecosystem functions as a kind of "natural labor")
vi) Forms of LK associated with long tenure in a place are lost and/or become less functionally relevant as the coupledness of an SES changes and the built environment intensifies; such losses can also be triggered by external drivers even (or especially) in the absence of built environment intensification (see hypothesis ii above)

## Conclusions

[Yet to be written]

## Acknowledgments

[Yet to be written]

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