ACT Publication No. 04-11

Linking Pixels and People

R.R. Rindfuss, S. Walsh, B.L. Turner II, E.F. Moran and
B. Entwisle

Reprinted from:

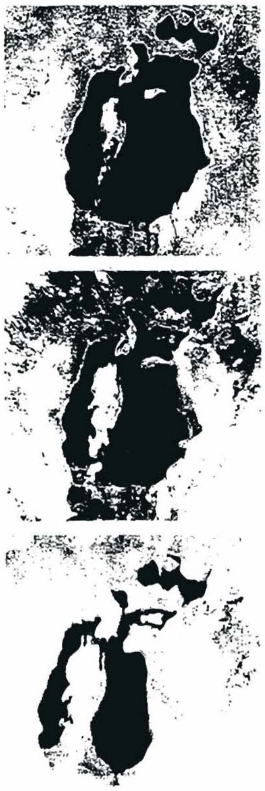
Land Change Science: Observing Monitoring, and Understanding Trajectories of Change on the Earth's Surface. **2004 Series: Remote Sensing and Digital Image Processing , Vol. 6 (G. Gutman, et al., eds.). Kluwer Acad. Publ. Pp. 379-394.**

REMOTE SENSING AND DIGITAL IMAGE PROCESSING

Land Change Science

Observing, Monitoring and Understanding Trajectories of Change on the Earth's Surface

Edited by
Garik Gutman,
Anthony C. Janetos,
Christopher O. Justice,
Emilio F. Moran,
John F. Mustard,
Ronald R. Rindfuss,
David Skole,
Billy Lee Turner II and
Mark A. Cochrane



CD-ROM INCLUDED

Kluwer Academic Publishers

Remote Sensing and Digital Image Processing

VOLUME 6

The titles published in this series are listed at the end of this volume.

LAND CHANGE SCIENCE

Observing, Monitoring and Understanding Trajectories of Change on the Earth's Surface

Edited by

GARIK GUTMAN
NASA Headquarters, Washington DC, U.S.A.

ANTHONY C. JANETOS
The H. John Heinz III Center for Science, Economics, and the Environment, Washintgon DC, U.S.A.

CHRISTOPHER O. JUSTICE
University of Maryland, College Park, U.S.A.

EMILIO F. MORAN
Indiana University, Bloomington, U.S.A.

JOHN F. MUSTARD
Brown University, Providence, Rhode Island, U.S.A.

RONALD R. RINDFUSS
University of North Carolina, Chapel Hill, U.S.A.

DAVID SKOLE
Michigan State University, Center for Global Change and Earth Observations and Department of Geography, East Lansing, U.S.A.

BILLY LEE TURNER II
Clark University, Graduate School of Geography, Worcester, Massachusetts, U.S.A.

and

MARK A. COCHRANE
Michigan State University, Center for Global Change and Earth Observation and Department of Geography, East Lansing, U.S.A.

KLUWER ACADEMIC PUBLISHERS
DORDRECHT / BOSTON / LONDON

A C.I.P. Catalogue record for this book is available from the Library of Congress.

ISBN 1-4020-2561-0 (HB)
ISBN 1-4020-2562-9 (e-book)

Published by Kluwer Academic Publishers,
P.O. Box 17, 3300 AA Dordrecht, The Netherlands.

Sold and distributed in North, Central and South America
by Kluwer Academic Publishers,
101 Philip Drive, Norwell, MA 02061, U.S.A.

In all other countries, sold and distributed
by Kluwer Academic Publishers,
P.O. Box 322, 3300 AH Dordrecht, The Netherlands.

Technical Editing:
LYNN H.J. HEDLUND
University of Virginia, College of Arts & Sciences, Charlottesville, U.S.A.

Cover Image: Change in the area of the Aral Sea (see also p. 258)

Printed on acid-free paper

Printed in the Netherlands.

TABLE OF CONTENTS

Editors: Abbreviated Profiles viii

List of Contributors xi

Foreword by Garik Gutman xxi

Section I LCLUC Concepts; National and International Programs

1. **The Development of the International Land Use and Land Cover Change (LUCC) Research Program and Its Links to NASA's Land Cover and Land Use Change (LCLUC) Initiative**
Emilio F. Moran, David L. Skole, and B.L. Turner II . . . .

2. **The NASA Land Cover and Land Use Change Program**
Garik Gutman, Christopher Justice, Ed Sheffner, and Tom Loveland 17

3. **Meeting the Goals of GOFC: an Evaluation of Progress and Steps for the Future**
John R. Townshend, Christopher O. Justice, David L. Skole, Alan Belward, Anthony Janetos, Iwan Gunawan, Johan Goldammer, and Bryan Lee 31

Section II Observations of LCLUC: Case Studies

Introduction – Observations of LCLUC in Regional Case Studies
David L. Skole and Mark A. Cochrane 53

4. **Forest Change and Human Driving Forces in Central America**
Steven A. Sader, Rinku Roy Chowdhury, Laura C. Schneider, and B. L. Turner II 57

5. **Pattern to Process in the Amazon Region: Measuring Forest Conversion, Regeneration and Degradation**
David L. Skole, Mark A. Cochrane, Eraldo A. T. Matricardi, Walter Chomentowski, Marcos Pedlowski, and Danielle Kimble 77

6. **Towards an Operational Forest Monitoring System for Central Africa**
Nadine T. Laporte, Tiffany S. Lin, Jacqueline Lemoigne, Didier Devers, and Miroslav Honzák 97

7. **Land Use and Land Cover Change in Southeast Asia**
Jay H. Samek, Do Xuan Lan, Chaowalit Silapathong, Charlie Navanagruha, Sharifah Masturah Syed Abdullah, Iwan Gunawan, Bobby Crisostomo, Flaviana Hilario, Hoang Minh Hien, David L. Skole, Walter Chomentowski, William A. Salas, and Hartanto Sanjaya 111

8. **Northern Eurasia: Remote Sensing of Boreal Forests in Selected Regions**
Olga N. Krankina, Guoqing Sun, Herman H. Shugart, Vyacheslav Kharuk, Eric Kasischke, Kathleen M. Bergen, Jeffrey G. Masek, Warren B. Cohen, Doug R. Oetter, and Maureen V. Duane 123

9. **Land Cover Disturbances and Feedbacks to the Climate System in Canada and Alaska**
A.D. McGuire, M. Apps, F.S. Chapin III, R. Dargaville, M.D. Flannigan, E. S. Kasischke, D. Kicklighter, J. Kimball, W. Kurz, D.J. McRae, K. McDonald, J. Melillo, R. Myneni,B.J. Stocks, D. L. Verbyla, and Q. Zhuang 139

10. **Mapping Desertification in Southern Africa**
Stephen D. Prince 163

11. **Woodland Expansion in U.S. Grasslands: Assessing Land-Cover Change and Biogeochemical Impacts**
Carol A. Wessman, Steven Archer, Loretta C. Johnson, and Gregory P. Asner 185

12. **Arid Land Agriculture in Northeastern Syria: Will this be a tragedy of the commons?**
Frank Hole and Ronald Smith 209

13. **Changes in Land Cover and Land Use in the Pearl River Delta, China**
Karen C. Seto, Curtis E. Woodcock, and Robert K. Kaufmann 223

Section III Cross Cutting Themes, Impacts and Consequences

14. **The Effects of Land Use and Management on the Global Carbon Cycle**
R.A. Houghton, Fortunat Joos, and Gregory P. Asner 237

15. **Land Use and Hydrology**
John F. Mustard and Thomas R. Fisher 257

16. **Land Use Change and Biodiversity: A Synthesis of Rates and Consequences during the Period of Satellite Imagery**
Andrew J. Hansen, Ruth S. DeFries, and Woody Turner 277

17. **Land Use and Climate**
Gordon B. Bonan, Ruth S. DeFries, Michael T. Coe, and Dennis S. Ojima 301

18. **Urbanization**
Christopher D. Elvidge, Paul C. Sutton, Thomas W. Wagner, Rhonda Ryzner, James E. Vogelmann, Scott J. Goetz, Andrew J. Smith, Claire Jantz, Karen C. Seto, Marc L. Imhoff, Y. Q. Wang, Cristina Milesi and Ramakrishna Nemani . . 315

19. **Land Use and Fires**
I. Csiszar, C.O. Justice, A.D. McGuire, M.A. Cochrane, D.P. Roy, F. Brown, S.G. Conard, P.G.H. Frost, L. Giglio, C. Elvidge, M.D. Flannigan, E. Kasischke, D. J. McRae, T.S. Rupp, B.J. Stocks, and D.L. Verbyla. 329

20. **Land Cover / Use and Population**
Ronald R. Rindfuss, B. L. Turner II, Barbara Entwisle, and Stephen J. Walsh 351

Section IV Methodological Issues, Modeling

21. **Trends in Land Cover Mapping and Monitoring**
Curtis E. Woodcock and Mutlu Ozdogan 367

22. **Linking Pixels and People**
Ronald R. Rindfuss, Stephen J. Walsh, B. L. Turner II, Emilio F. Moran, and Barbara Entwisle 379

23. **Modeling Land-Use and Land-Cover Change**
Daniel G. Brown, Robert Walker, Steven Manson, and Karen Seto 395

Section V Synthesis and Lessons: Biophysical Change and Beyond

24. **Land-Use and Land-Cover Change Pathways and Impacts**
John F. Mustard, Ruth S. DeFries, Tom Fisher, and Emilio Moran 411

25. **Integrated Land-Change Science and Its Relevance to the Human Sciences**
B. L. Turner II, Emilio Moran, and Ronald Rindfuss 431

26. **Research Directions in Land-Cover and Land-Use Change**
Anthony C. Janetos 449

CD-ROM – Index of color images 459

LINKING PIXELS AND PEOPLE

RONALD R. RINDFUSS[1], STEPHEN J. WALSH[2], B. L. TURNER II[3], EMILIO F. MORAN[4], BARBARA ENTWISLE[1]

[1]University of North Carolina, Department of Sociology, Chapel Hill, NC 27599
[2]University of North Carolina, Department of Geography, Chapel Hill, NC 27599
[3]Clark University, Graduate School of Geography and George Perkins Marsh Institute, Worcester, MA 01610
[4]Indiana University, Center for the Study of Institutions, Population and Environmental Change, Bloomington, IN 47405

1 Introduction

Integrated land-change science (Turner 2002) seeks to join remotely sensed (pixels), biophysical (terrestrial), and social science (people) data. The history of joining these three fundamentally different data types is remarkably short. The effort focused on the social science-remote sensing data beyond photogrammetrics has only emerged over the last decade or so. The organizers of the National Academy of Science volume *People and Pixels* (Liverman et al., 1998), which was designed to provide illustrations of studies that joined the two types of data, had to scramble to find a sufficient number of experts and research to fill a workshop and the resulting volume. Indeed the careful reader of that volume might wonder about the extent to which some chapters actually link social science and remotely sensed data. The paucity of robust pixel-people studies is unfortunate given the increasing need for such linkages as global environment change, biocomplexity, and sustainability science turn to questions of the coupled human-environment system.

This chapter reviews some of the issues that arise when joining remotely sensed and social science data.[1] The focus is methodological, not substantive. The goal is to identify, describe, and review methodological challenges, recognizing that the solutions will be driven to a large extent by a researcher's substantive questions and scientific goals. As noted, the history of joining data on pixels and people is short. Hence it is highly likely that some key questions have not even surfaced, a point to which we return in the conclusion of the chapter. Also, we do not address potential ethical issues that might arise when joining remotely sensed and social science data except to note here that ethical issues definitely do arise and researchers need to be careful about them (see discussion by Rindfuss and Stern 1998). Readers must remember that the assessment offered here is a start and not a finish.

The chapter opens with perhaps the most fundamental question that researchers interested in joining people and pixels must face: where to begin? There is no necessary

---

[1] We speak in terms of pixels because the typical study uses spatial data from satellites, which comes in raster form. We recognize, of course, that one might want to link to spatial data, such as soil maps, that might come in the form of polygons. The general points we are making about linking to raster data would also apply to polygons.

G. Gutman et al. (eds.), Land Change Science, 379–394.

parallel between social units and land units. Moreover, coverage of one does not necessarily guarantee coverage of the other. The first section discusses the implications of the starting point, land or people. Then, linking relations (e.g., ownership, use, or access) are addressed. The need for temporal depth presents challenges on both sides of the land-people equation, and these are discussed next. We then turn to challenges associated with the joining of diverse disciplines, which is often a necessary part of joining people and pixels. The chapter concludes with an overview of new topics and challenges that will need to be addressed as the field develops. To date, researchers linking people and pixels at finer scales have tended to focus on land use in rural areas, especially in frontier environments; there is a need to encompass urban areas as well.

2 Starting Point: People or Land?

In linking pixels and people, an early decision that researchers must face is whether to start with people and try to link with pixels, or start with pixels and try to link to the people affecting those pixels. Where one starts is determined by the research question, the data available, and in many instances the disciplinary orientation of the researcher. Where one starts is consequential for the kinds of statements that can be made, and the kinds of conclusions drawn.

There are important differences between the types of data typically available for land and those typically available for people. Remotely sensed data provide continuous coverage of land within some predetermined boundaries, from relatively small areas such as a county or a watershed to relatively large areas such as a continent or the entire globe. In contrast, social science data tend to refer to discrete units: individuals, households, organizations, and nations. Social science data are rarely global in reach. When they are, such as world demographic and economic data, they are aggregated (e.g., by the United Nations) from country supplied data for countries that vary considerably in their quality. The scales at which social science data are reported varies, but often refer to administratively defined units such as counties, provinces, or countries. Social science analysis typically draws on data referring to a smaller unit of social organization such as a household. More often than not, these scales are inconsistent with those of land studies. Although governments make and enforce policy for administrative territories such as nations, provinces, and municipalities, there is no spatial unit that corresponds to an individual, household, or business. At finer scales, the challenge is to marry continuous land data with discrete data on social units (Rindfuss et al., 2003a).

Considerable experience exists in linking biophysical and spatial data sets to one another (e.g., overlays of different coverages in a GIS) and in linking social survey and administrative data sets (e.g., merging data sets for different units of observation for hierarchical statistical analysis). For each, there are critical theoretical and technical issues, such as accurately overlaying the pixels from the various images with each another to make sure they cover the same land units, deciding the successor to a household, business, religious group or governmental body when the original unit subdivides or fissures, or linking a person to one context (e.g., residence) when they actually live their lives in multiple contexts as determined by residence, work, seasonal work, vacations, and the like. While acknowledging that these and other complex issues exist in creating linked data sets within domains, they will not be discussed here. Rather, we focus on the issues arising out of moving *across* these types of data sets to link people and pixels.

Suppose we choose land as our starting point. Starting with land offers advantages in research where there is a strong biophysical component being considered as part of the research design, and where the quality of the people data is of poor quality. We might choose a biophysical unit, such as a landscape or watershed, or a territorially defined political unit such as a county or district thereby permitting a link to detailed biophysical data and/or detailed census data collected for that land unit. If we choose a biophysical unit, the challenge is to identify and assemble data for the relevant social groups. There is no social unit that parallels a landscape or watershed, for example. Starting with land provides the potential for continuous coverage within the boundaries of the land units chosen, but the people and organizations to which links are made may not represent a coherent collection of people or organizations.

We might also sample land units, and hence their associated pixels in a satellite image.[2] This is not uncommon at relatively fine scales, such as a field plot. Examples include Moran et al. (2003) and Walsh et al. (2003). Once a sample has been drawn, the research design challenge becomes (a) the identification of the most proximate decision makers for the land sampled (e.g., through ownership records at a local government office), (b) locating and obtaining relevant information (e.g., from those owners directly, or indirectly through records), and (c) locating and obtaining relevant information about land cover, land use, soils, and other biophysical factors that will permit interpretation of the remotely sensed data. The link to people might be through some type of individual or group interview, or it might involve administrative records, such as land transfer data.[3] A potential problem is that the ability to acquire the relevant information may depend on the characteristics of the people involved. For example, owners of the sampled land units are likely to vary with respect to a variety of characteristics, such as type (individual, household, extended kin group, business, limited partnership, NGO, or government), location (on the land unit, near the land unit, quite distant from the land unit including in another country), and economic or wealth status. These and other characteristics are likely to be related to the ability to locate and obtain the necessary data. Others things equal, we expect businesses, and wealthier and more distant individuals to be the most difficult entities from which to obtain data. To the extent that non-response is significant, and to the extent that it is selective in the way we have just described, researchers need to consider the implications for bias. Put differently, if non-response is substantial and selective, then the resulting data set is likely to be biased.

Starting by sampling people (individuals, households, organizations, and so forth) and then linking them to the land parcels that they own or use also raises problems related to coverage and data quality. The link to the land might be made through respondent interviews, administrative data, or informants. Again, there will be issues of respondent cooperation and quality. The availability of data on land may depend on the characteristics of that land. For example, often there is more ambiguity about ownership and use rights to

---

[2] Technically, pixels refer to the smallest unit of observation in a remotely sensed image. For linguistic ease here, we also use "pixels" to refer to land units as viewed through a rasterized scope.

[3] In using administrative records, the issues of respondent non-response (e.g.Groves 1989; Groves and Cooper, 1998; Freedman, Thornton and Camburn, 1980; Lessler and Kalsbeek, 1992) recede, but one then needs to worry about the coverage and quality of the administrative data. People supplying the administrative data might have an incentive to not be completely forthcoming (e.g., to avoid taxes). Administrative records are also frequently out of date.

forest lands than to lands in other coverage. An additional important point is that when people are sampled, the land parcels linked to the sampled people are unlikely to be contiguous; instead they are likely to be a patchwork of parcels surrounded by other unlinked parcels. The surrounding unlinked parcels might belong to people who were not interviewed or might result from missing data in administrative records. Alternatively, the surrounding unlinked parcels might belong to people (individuals, households, or organizations) that were not in the sampling frame used by the study. For example, the sampling frame might be all individuals, households and organizations in a given district. Thus land owned or used by those outside the district would not be linked or included in the study. No matter what the reason, starting with people is likely to lead to a patchwork of linked land units which is unlikely to have any ecological or environmental coherence, and may introduce bias from the perspective of the land that is not linked.

As more case studies accumulate, the implications of starting with land or people will need to be carefully examined. Some studies in tropical forests begin with land (e.g. Moran et al., 2003; Walsh et al., 2003), while others begin with nucleated villages or households (Rindfuss et al., 2003b; Turner and Geoghegan, 2003). This decision is often a result of the way the settlement pattern itself has come into being, and/or the availability of relatively good quality property boundary data that allows for a one-to-one link between a social unit (household) and a land unit (parcel). In communities, such as *ejidos*, where land is held in common this is a less likely option (unless customary behavior has resulted in customary recurrent use of the same land area by individual families). If one draws a sample of land units, say field plots, except under unusual circumstances, the owners of those plots will not yield a representative sample of households living in proximity to those plots. For example, landless households, as well as households renting land from absentee landlords, would be excluded. Similarly, a sample of social units will not generally yield a representative sample of land units. For example, not all land is owned or used by households. Descriptive statements about land based on a sample of social units will not generally agree with descriptive statements based on a sample of land units. Similarly, descriptive statements about social units based on a sample of land units will not generally agree with descriptive statements based on a sample of social units. Clearly, making explicit how a researcher is making the link, and with which unit they are beginning is an important starting point for synthesis efforts in order to determine whether cases are indeed comparable. When attempting to draw lessons and generalities from the entire set of case studies (see Geist and Lambin 2002), it will be important to critically address the extent to which differences in the base sampling strategy affect the outcomes that are included in the synthesis of case studies.

3 Selection of the Linking Relation

Linking pixels and people requires a linking relation. Suppose one wishes to join a village and a village territory. The linking relation might be an administrative or tax boundary, and the linking unit, the administrative village. Suppose one wishes to link a household and a field plot. The linking relation might be ownership, and the linking unit the owned land parcel. Linking relations can be complex. Consider, for example, the people who have the most proximate decision making power over a given collection of pixels or a land unit. In an area where land is clearly titled, the "person" (e.g., individual, household,

business, NGO or government) with the most proximate decision making power is the land owner, even though other individuals or institutions may exercise decision-making power, such as those who might rent the land, zoning that regulates permissible uses of the land, or the influence of market forces (i.e. demand) for products from the land.[4] When land is not clearly titled, identifying those with the most proximate decision making power can be problematic.

Just as there are numerous units of observation on either side of the people-pixel divide, there are also numerous potential linking relations such as managing the land, owning the land, renting the land, using the land for recreational purposes, and so forth. In addition, linking at one level does not guarantee links at other levels. Within each domain, there may be a hierarchy. Individuals are embedded within households, within villages, within administrative units all the way up to the country or region itself. Field plots are embedded within patches, within landscapes, within regions, and so forth. Much effort has been put into linking households and field plots, as described below. However, aggregating household-plot links will not generally yield a meaningful link between, say, villages and landscapes. In other words, linking people and pixels at one point in the hierarchy does not create parallelisms elsewhere. This section of the chapter briefly reviews some of the issues that arise with respect to linking relations, beginning with the "easiest" case of direct ties between land managers and specific land parcels.

In cases of land ownership and customary usufruct rights, individual households or land managers can be linked specifically to land parcels; this is also true of ranching or stocking systems linked to private ownership (e.g., Archer forthcoming). Farming systems with direct ties between land managers and specific land parcels would seem to alleviate the linkage problem. Even in this situation, the user-parcel relationship can be quite complex, however. In some cases, multiple, discontinuous parcels are cropped by one household and a single parcel may be cropped cooperatively by several households. Rindfuss et al. (2003b) describe a multi-pronged approach to the matching of households and plots in this situation involving household interviews, group interviews, parcel boundaries superimposed onto aerial photographs. In other cases, spatially continuous parcels may be used in a crop-fallow cycle in which forest succession makes parcel demarcation difficult (Moran et al., 2002). Turner and colleagues (2001) treated this problem in southern Yucatán by sketch mapping entire parcels in various stages of succession and linking them to satellite imagery by obtaining a GPS reading of the parcel. Even more complexity is introduced in those cases where parcels in different stages of succession are rented or borrowed by neighbors from the land "owner." In these cases, the household from which social information is drawn may not be that which determined the cropping strategy. Laney (2002) addressed this problem in Madagascar by undertaking household surveys in which the history of land borrowing was detailed, and then linked to the overall imagery of the lands enjoined by the village. Further, in some settings, land ownership might be something that the owners do not want divulged in an interview setting (e.g. Rindfuss et al., 2003b).

Another variation is to move away from the most proximate land users and obtain data from a more highly aggregated unit, such as a village or a district. One version of this strategy uses village-level focus groups or rapid rural appraisals to gather data at the village

---

[4] Clearly, a complex, multi-purpose research design will want to have links to these more distal decision makers. Many of the issues we address for the most proximate decision makers will also apply to the more distal ones.

level (e.g. Fox et al., 2003) linked to satellite imagery of the village lands. Alternatively, census level socioeconomic data collected for political or administrative units, usually at a higher level of social aggregation such as a county or municipality, are linked to remotely sensed data of the same unit (Rosero-Bixby and Palloni, 1998; Wood and Skole, 1998; Geoghegan et al., 2001; Seto and Kaufmann, 2003). Both of these strategies have the virtue that they reduce the costs to the researcher of collecting the social science data. Focus group information, however, typically produces "reduced" form data, often qualitative only, while census data reduces the questions of the study to those that are possible based on preexisting data collected for other purposes. The drawback to both approaches, but especially the census/district level design, is the now classic argument that there is no necessary relationship between relationships at the district level and relationships at the individual, household or organization level (Robinson 1950). Relationships between land and people may be scale-dependent (Walsh et al., 1999). Further, the census approach has a scale problem noted by McCracken and his colleagues (2002). The size of areal units is inversely related to population density, in order to protect the confidentiality of individuals and households. In many rural areas, where density is low, the size of the areal unit is typically larger than the analyst might want, because county or district units are spatially very large in low population regions.

As just explained, even in farming systems with direct ties between land managers and specific land parcels, linkage can be a problem. In many parts of the world land is not clearly titled or is held as common property or with common access rights. At the extreme, herders move their stock from place to place on a daily or seasonal pattern, seeking adequate feed and water, and creating special problems for linking people and pixels. BurnSilver and her colleagues (2002) addressed this issue in the Kajiado District, Kenya, by joining herders on their daily grazing paths, using a GPS unit to record the spatial location of these paths, providing a direct link of the people to the specific lands used. In contrast, Robbins (1998) made this linkage by combining village-level data collection with the common access areas used by the villagers. In short, when land is not clearly titled, identifying those with the most proximate decision making power can be even more problematic than when land is clearly titled. As a result, the investigator designing a study for such a site will need to know the formal and informal rules governing land use in the area, through preliminary field trips and/or careful reading of the relevant research literature.

A different type of problem emerges because not all people who have an effect on the land live on or close to the land. Companies that may exploit the land (e.g., logging, mining) may be based at some distance. Likewise for policy-making bodies. But even at a finer scale, individuals who impact the land may not live on or close to it. The general problem is how to identify these distal decision makers, obtain data from them, and then make the link to specific land parcels. To illustrate the issue we consider tourists, but note that the problem is far more general than just tourists.

Many of the places where people go for vacations tend to be fragile environments, such as coasts, areas rich in flora and/or fauna diversity, and areas on the edge of places that are geologically spectacular (such as Yellowstone or the Grand Canyon in the U.S.). Indeed eco-tourism is being suggested as a way to save ecologically important regions, particularly those in developing countries. While the link to hotel owners and eco-tourism operators might seem straightforward, the hotel owners are probably located quite some distance from the site, thus having very little direct feedback on the impact of their decisions on the landscape. National and international governing bodies will frequently have land use rules and regulations applied to such areas, but may sometimes have limited ability to enforce the rules meant to protect such habitats, or lack the involvement of local people to ensure enforcement. Commonly, people will live in these reserves or protected areas – sometimes legally and sometimes in violation of existing regulations. Liu and his colleagues' work illustrates the importance of understanding human influences in such settings – in his case the Wolong Nature Reserve (Liu et al., 2001). Liu's work also illustrates the difficulty in establishing micro links in reserves and protected areas (Liu et al., 2003). Even more difficult is linking remotely sensed data, and changing land cover, for these fragile and vulnerable areas with vacationers who come for a week or two. The vacationers who use the fragile landscape for short periods are affecting land cover change, but they are likely to live and work quite some distance from the land being affected. No less complex are the links at larger scales, such as the broad impacts of eco-tourism in parks across the world. In such cases, a complex array of variables may be relevant to understanding how short-term visitors, coming in large numbers sequentially over a short vacation period, have aggregate impacts much greater than comparable numbers living in a similar area on a year-round basis. While this is a research question that has not been addressed to date, it is a reasonable hypothesis on the basis of the greater likelihood of having feedbacks to the latter, and an absence of those same feedbacks to the short term visitors.

4 Temporal Depth and Associated Complexities

People-pixel links, of course, are far more complex than land users-parcel relationships. They also involve temporal dynamics and other change complexities, both in land-cover and causes of use-cover change. Consider, for example, the geophysical complex light phenomenon known as reflectance. A parcel is made up of biophysical factors such as soils, water, plants, and buildings. Each of these reflects light in its own particular way, and these data fluctuate as they interact with each other (dry vegetation reflects very differently from moist vegetation, likewise for soils and road surfaces and even roofs of buildings). Thus, the importance of temporal depth, or multitemporal data, to properly capture the reality on the ground as it is differentially affected by seasonality-related factors.

Archived satellite data and historical aerial photography are rich sources of information that can be processed to yield temporally-deep land cover change maps and other products for selected points in time and for the generation of change-images that depict, for example, "from-to" changes of land cover types, and as well as changes in variables such as greenness, leaf area, or plant biomass (Macleod and Congalton, 1998). Aerial photography may extend the satellite image time-series in time, offer alternative spatial resolutions or improved minimum mapping units, and provide the analyst with vertical and three-dimensional perspectives for measurement and interpretation. Also, low- and high-oblique air photos provide coverage of large geographic areas and can be aligned with certain geographic features having specific orientations (e.g., looking at land cover up or down valleys or along political or functional land boundaries). Scan-digitizing individual frames of aerial photography and then correcting and combining them into a seamless image mosaic can effectively transform the remotely sensed data from analog to digital and prepare the data set for image processing using similar approaches and techniques as used with satellite data.

The temporal depth of the archived data provides historical context and offers "snapshots" in time of landscape characteristics, possibly linked to people through longitudinal surveys, to place through georeferencing procedures, and to the environment through field-based vegetation and soil surveys. Socioeconomic and demographic data collected as part of a longitudinal survey may be retrofitted to relate in time to acquired remotely sensed data by assembling an image time-series in which selected imagery is biased towards survey periods and events that might have occurred prior to the survey, but has implications for the obtained survey results (e.g., droughts, migration events, or changes in road/river accessibility). Place characteristics might involve the geometric correction of the acquired imagery, the transformation of the data from path-row coordinates into UTM (Universal Transverse Mercator) Earth coordinates, and the relative or absolute alignment of multiple images within a time-series. Environment characteristics might involve the use of pattern metrics and a land cover classification in which the spatial organization or structure of land cover types are tracked across an assembled image time-series. Operating at the landscape, class, or patch scales, pattern metrics include such measures as juxtaposition, perforation, fragmentation, and edge characteristics -- useful descriptors of how LCLUC composition and patterns are changing as an indication of landscape form and function (McGarigal and Marks, 1993).

Among the challenges of using an image time-series for capturing compositional and pattern dynamics is how land cover will be categorized for historical periods. Classification approaches (a) use training data to compare areas of known cover-types to unknown spectral responses through supervised approaches, (b) search for "naturally" occurring spectral responses and their possible convergence into spectral clusters through unsupervised approaches, or (c) integrate the supervised and the unsupervised approaches through hybrid schemes. In the supervised approach, field data, aerial photography, and/or other forms of land cover "control" are needed to define the location and composition of "training" areas, whereas in the unsupervised approach, cluster labeling of spectral patterns as to land cover type generally relies upon statistical measures of spectral association and separability as well as field or imagery data to give landscape meaning to the clustering statistics and the defined spectral classes. The hybrid approach is often used as a way of overcoming the limitations of each approach, and taking advantages of the strengths of the first two approaches (Mausel et al., 1993; Moran et al., 1994; Moran and Brondizio, 1998).

Characterizing landscape state and conditions variables for historical periods often increases the complexity of the classification process, because field data frequently are not available and/or aerial photography may be absent. Therefore, remote sensing analysts often opt for generalized classification schemes to minimize errors of commission and omission, rely upon relative accuracies and not measures of absolute classification accuracy, or search for alternative ways for validating historical data sets using ecological and/or demographic techniques (though very rarely done). Such approaches might use correlated ecological data, retrospective survey data to construct landscape chronologies, or the construction of "panel" data sets so that land use histories can be derived and illogical land cover pixel-derived trajectories, such as forest-to-water-to-forest occurring within a 3-year period, can be interpreted as classification error, because the change magnitudes and directions are believed to be improbable, given local site conditions and hypotheses about land cover dynamics.

Even for contemporary remotely sensed imagery, the spatial resolution of the data affects the researcher's ability to validate land cover classifications. For instance, normal procedures generally involve random, stratified random, or systematic samples arrayed across a classified landscape and often weighted by percent area of each class. Using high resolution imagery as a field guide or a GPS to navigate to preselected and encoded points, quadrant or line transects are often used to characterize the composition and pattern within pixels. Using Landsat TM data, having a 30 x 30 m pixel, for its optical channels, both field survey approaches have obtained acceptable results. But for imagery of large spatial resolutions such as the 1.1 x 1.1 km pixels of NOAA's AVHRR (Advanced Very High Resolution Radiometer) or the 250 x 250 m and 500 x 500 m pixels of MODIS, more complex field protocols may be needed because of the grain size of the pixel.

Assuming that historical reconstructions of land-cover are robust, major errors may follow if the study of the current socioeconomic conditions are "back-casted", assuming stationarity in the driving forces of change. As Kelpeis and Turner (2001) demonstrate, the kind, source, and rates of deforestation in the southern Yucatán have changed during modern history in relationship to the vision that the Mexican government has held of it: a dismissed wildland, an extractive forest frontier, an agricultural development zone, and an archaeo-ecotouristic region.

Over shorter time periods, say a decade or two, the issue of land user recall looms large. The basic question is the extent to which people can remember how they used the land during various time periods. To the best of our knowledge, there has been relatively little work examining this issue (though there is a considerable literature in the social sciences on informant recall). The more general issue of how well people recall various things has yielded the conventional wisdom that respondents can recall events like marriages, births or migrations for 20 or more years in the past, but they cannot accurately recall their prior attitudes. This suggests that we cannot simply assume that people can recall land use many years in the past– though they may have a very good idea of what they did this year and even last year. In some unpublished work while designing a questionnaire for Nang Rong Thailand, Walsh, Entwisle and Rindfuss found that people reported having trouble recalling how they used their land parcels more than one or two years in the past. This was based on respondents' perceptions, and there was no attempt to use outside data to see if the respondents's perceptions seemed accurate. Moran and colleagues routinely use time-series aerial photos and Landsat TM images for a particular parcel to assist the informants in reconstructing their land use history (McCracken et al., 1999, 2002; Moran et al., 2001, 2002; Brondizio et al., 2002). They find that this method is helpful at the parcel level. It is possible to have an approximate idea of the land cover for a series of time periods, and ask the respondent about land use and cover at these time points. For example, the interviewer can point out that in a particular part of the parcel in 1985 there is an area that is forest-like in appearance and that it is likely either cocoa or 10-year secondary succession. The respondent can then answer which it was. Or, to continue the example, the interviewer can point out that in another part of the parcel an area was being intensively cultivated with some open-field crop. Again, the farmer may be able to resolve this question by remembering the location of the patch and his strategies during that period, say corn or cassava (since they have different soil fertility requirements).

For relatively long time periods, mapping land cover change is further exacerbated by the possible non-stationarity of the landscape and the nature of the spatial autocorrelation of the mapped cover types. If, for instance, the landscape is becoming increasingly wet, because of an upward trend in the precipitation levels, finding coarse changes in plant biomass may be biased towards longer analysis periods, when dry and wet conditions occur over anniversary dates, thereby affecting the greenness levels recorded in the imagery. And, the ordering of values as a consequence of location (spatial autocorrelation) might impune accuracy assessments for clustered samples and bias results for change-detections for image dates within the same season or for periods when change is unlikely to occur because of the periodicity of land cover change.

5 Multi-Disciplinary Issues

To engage in multi-disciplinary science means traversing the theories, practices, languages, orientations, perspectives and histories of sometime allied fields but also of distant sciences. However difficult the journey, the research questions that engage the land cover/use research community require the integration of social, natural, and remote sensing-GIS sciences and their perspectives. Multi-disciplinary teams are often assembled to accommodate this diversity of expertise by including scientists that have training and experiences in one or more fields of study so that collectively, broad swaths of the social, natural, and spatial sciences are represented. While the nature of the multi-disciplinary team may evolve over time to address new questions and to take on new research opportunities, core strengths in the human-environment-spatial domains are fundamental. Because of the relevance of local culture and context, a regional specialist, often a collaborator from an in-country or local institution also participates on the team as a core area of emphasis. Further, technical expertise is critical and so statistical programmers, spatial programmers, spatial analysts, and survey specialists are among the support group that is critical to the success of the research venture and to the overall performance of the team. Beyond research, members of university-based teams also have training responsibilities that may include developing in-country capacities, developing spatial and demographic survey teams for data collection, and instructing students about research methodologies and protocols, including research ethics and issues of data confidentiality.

A framework that integrates, for instance, soils, climate, and hydrology as descriptors of the environment with human causes and consequences, represented and integrated within a spatially-explicit context afforded through remote sensing and geographic information systems, supports many of the cross-cutting issues that seek to integrate people, place, and environment. To support such a framework, scholars impose theories and practices from their disciplines to help form questions and frame hypotheses, and often embed disciplinary practices into the analytical design. Among those topics are questions of the directionality of relating people to the environment. Do we begin with people and link to the land, or do we begin with the land and link to people? Generally, spatial, landscape and natural scientists may wish to initiate research by framing questions that begin with the land, represent landscape characteristics as continuous surfaces, and reference features within Earth coordinate systems. Often, these scientists may see the environment or the spatial-temporal pattern of land cover as the dependent variable. Social scientists may wish to start with people and represent them at discrete locations, possibly referenced through areal units of aggregation. Often too, social scientists might seek to explain a socioeconomic and/or demographic characteristic of a household or community, transforming continuous geographic and/or biophysical variables into discrete values for compatibility. As discussed earlier, the starting point of the analyses – land or people -- creates different selectivities that need to be handled through different analytical designs.

Data quality is important to land cover and use characterization that is subject to debate and disciplinary approaches. In the remote sensing community, land cover is normally assessed through an error matrix that compares the remotely-sensed classification to the same classes mapped through a data source of presumed higher accuracy. Standard protocols call for the generation of class accuracies that reflect omission and commission errors and errors to the overall classification as a consequence of chance (i.e., the kappa statistic, Hudson and Ramm, 1987; Congalton 1991). An interpretation of off-diagonal errors is used to assess the nature of the confusion between classes and to possibly consider the merging of classes to minimize misclassification. Also, remote sensing specialists often use non-spectral information such as digital elevation models in the classification process either as an additional classification vector operating at the pixel level or in a post-classification stratification where topographic settings separate spectral classes based upon location and landscape strata. Non-spectral data are used to increase the quality of the land cover map. But by including the non-spectral, ancillary data, endogeneity may result when the derived land cover classifications are used in an assessment or modeling activity in which terrain is included or a variable such as soil moisture potential is used that may be highly correlated with topography.

Classification accuracies of Level-1 (e.g., forest, agriculture, urban) mapping are generally around 90 percent, but accuracies in the 60-80 percent levels are not uncommon for more detailed classifications (e.g., deciduous forest, cropland, residential). Also in an attempt to improve classification accuracy of land cover types, multiple time periods may be consolidated into the same classification by clustering pixels through multiple spectral space, beyond the spectral channels of a single image scene. Often, spectral derivatives in the classification process such as greenness measures derived through vegetation indices are used. Finally, it is relatively uncommon for accuracy reports to contain a full error audit including pre- and post-processing, or statistics that report the spatial structure of classification error (Brown et al., 2000).

Answering land cover and land use change questions requires the integration of the social, natural, and spatial sciences. This, in turn, creates its own set of challenges. Different disciplines have different "defaults" in terms of what questions are interesting to investigate and the best way to address them. Starting point–land or people–is certainly an example. Whereas those trained in the social sciences will tend to start with people, those trained in the natural and spatial sciences will tend to start with the land. A related difference is that those trained in the social sciences will tend to prefer a relatively micro approach, focusing on people and households where the science and data are strongest. Relationships between biophysical, spatial, and social variables are scale dependent (Walsh et al. 1999). Something seemingly simple such as a match rate between households and field plots can be measured in different ways, and the different disciplines may have differing perspectives on which one is "right." In the case of a match rate, the value will depend on how one sees the task, the conceptualization of the population at risk, and the definition of the denominator in terms of people or land. Prevailing norms about "best practice" also vary between disciplines. For example, the statistical modeling of causal influences and the proper treatment of potential endogeneity is a major issue right now in the social sciences, especially the economic and demographic sciences. Multi-disciplinary teams are well positioned to make progress at the interface of the social, natural, and spatial sciences, but the challenges are large and at the same time, sometimes subtle and difficult to see.

6 Next Challenges

We conclude by returning to a theme from the introduction. The history of linking pixels and people is short, and the research community will continue to develop methodological and technical solutions. We conclude by discussing some research areas that could involve the linking of pixels and people, areas that are potentially important land use change research topics, and yet thus far have received limited research attention. We expect that part of the reason for this involves the difficult pixels and people linkages that might be required.

Most of the projects that have so far linked people and pixels at the micro level have done so in rural areas, primarily in developing countries, and quite frequently in frontier or recently frontier areas. Conversion of forest into agricultural use has been a principal focus, and typically the agriculture involved growing crops for subsistence use. Commercial crops have tended to receive less attention, but there are examples such as cassava in Thailand (Rindfuss et al. 2003b) and chilis in Mexico (Turner and Geoghegan, 2003). Progress has been made in devising ways to link people and pixels in rural areas of developing counties, but, as we have noted repeatedly throughout this paper, there are many methodological issues that require further work before the field should feel secure in its approaches. We will not repeat those issues here, but rather point to some challenges that are likely to arise as the land science community links more diverse groups of people and pixels.

Once one moves beyond subsistence agriculture and similar types of land use (hunting and gathering, pastoral activities, or wood collection for cooking) to land use that explicitly involves an exchange of money or other goods, then there are two groups people (individuals, households, and various corporate groups) involved. For linguistic ease, we will use the "producers and consumers" terminology, aware that for some purposes the connotations break down. Axinn and Barber (2003) refer to the distinction between direct and indirect consumption of environmental resources that emerges with specialization, industrialization, urbanization, and the expansion of markets from local to regional to global.

Above we gave the example of vacationers affecting land use in interesting but fragile settings. There are numerous other potential examples. A Midwest U.S. farmer growing corn that might be consumed in a variety of countries around the world, or fed to cattle, which in turn could be consumed in an assortment of places outside the Midwest U.S. Most shrimp consumed in the U.S. is farm-raised in Latin America and Asia. Affluent Europeans might have their kitchen cabinets built from koa wood from Hawaii, mahogany from Vietnam, or zebra wood from central Africa. As world demand for coffee increases, farmers in Kenya or Brazil might react by planting more coffee, and if the medical community ever has definitive proof that drinking coffee injures one's health, land use in the world's tropical and subtropical areas would change appreciably.

The general point is straightforward. As consumers within countries and globally make decisions about what to buy, this affects how producers make land use decisions. Sometimes the consumer-land use change linking relations are concentrated and clearly evident: a religious organization (or a corporation) is building a new church (a new corporate headquarters) that requires a substantial amount of ebony and a hectare of forest is deforested (harvested) in Mauritius. (See Lutz and Holn 1993 for a discussion of world market demands and deforestation in Mauritius.) Here one could begin to imagine a research design that linked the consumption decision to the land use decision to the pixel classification change. Sometimes the consumer-land use change linking relations are very diffuse: a change in tastes such that consumers in affluent countries are willing to pay more for produce that is locally grown, organic, and freshly picked. While it seems self evident that diffuse changes in consumer preferences and purchasing behavior will produce diffuse land use changes, we know of no studies that have linked diffuse groups of consumers to changes in land use as measured in pixel classification change. We would hypothesize that as markets become more global and interdependent, there will be a tendency for land use decision makers to respond to global markets and use their land to maximize profits rather than for sustenance. Given that these land use changes may have detrimental effects globally (deforestation is a good example) or locally (the environmental problems associated with shrimp and prawn farms), it will be important to go beyond "self evident" understanding[5] and examine the pathways that link diffuse change in consumer behavior to change in land use.

Another challenge will be to bring the lessons learned in linking people to pixels in rural areas to urban areas. Given that 47 percent of the world's population already lives in urban areas, and that percentage is projected to grow to 60 percent by 2030 (http://www.un.org/esa/population/publications/wup2001/WUP2001report.htm), improved understanding of urban land use change is important. So far studies linking social science data with remotely sensed data for urban areas have done the linkages at fairly macro levels, such as district or county (e.g. Seto and Kaufmann, 2003). While these studies have yielded interesting findings, it will also be important to link urban land use decision makers to the parcels and pixels over which they exercise decision making authority.

7 References

Archer, E.R.M. Forthcoming. "Beyond the "climate versus grazing" impasse: using remote sensing to investigate the effects of grazing system choice on vegetation cover in the eastern Karoo." *Journal of Arid Environments*.

Axin, William G. and Jennifer S. Barber. 2003. "Linking People and Land Use." In Jefferson Fox, Ronald R. Rindfuss, Stephen J. Walsh and Vinod Mishra, eds., *People and the Environment: Approaches for Linking Household and Community Surveys to Remote Sensing and GIS*. Boston: Kluwer Academic Publishers. Pp 285-313.

Brondizio, E. S., McCracken, S., Moran, E. F., Siqueira, A.D., Nelson, D.R., and Rodriguez-Pedraza C. (2002). "The Colonist Footprint: Towards a Conceptual Framework of Deforestation Trajectories Among Small Farmers in Frontier Amazônia. In C. Wood and R. Porro (eds.) *Land Use and Deforestation in the Amazon*. University Press of Florida, Gainesville. Pgs. 133-161.

Brown, D.G., Duh, J.D., and Drzyzga, S. 2000. "Estimating error in an analysis of forest fragmentation change using North American Landscape Characterization (NALC) Data." *Remote Sensing of Environment*, 71: 106-117.

BurnSilver, Shauna B., Randall B. Boone, and Kathleen A. Galvin. 2003. "Linking Pastoralists to a Heterogeneous Landscape: The Case of Four Maasai Group Ranches in Kajiado District, Kenya." In

---

[5] The history of science is littered with examples of self evident understandings that later proved not to be the case. "The world is flat" is perhaps the best one.

Jefferson Fox, Ronald R. Rindfuss, Stephen J. Walsh and Vinod Mishra, eds., *People and the Environment: Approaches for Linking Household and Community Surveys to Remote Sensing and GIS.* Boston: Kluwer Academic Publishers. Pp 173-199.

Congalton, R. G., 1991. "A review of assessing the accuracy of classification of remotely sensed data." *Remote Sensing of Environment,* 37: 35-46.

Freedman, Deborah S., Arland Thornton, and Donald Camburn. 1980. "Maintaining Response Rates in Longitudinal Studies." *Sociological Methods and Research.* 9(1):87-98

Fox, Jefferson, Terry Rambo, Deanna Donovan, Le Trong Cuc, Thomas Giambelluca, Alan Ziegler, Donald Plondke, Tran Duc Vien, Stephen Leisz, and Dao Minh Truong. 2003. "Linking Household and Remotely Sensed Data for Understanding Forest Fragmentation in Northern Vietnam." In Jefferson Fox, Ronald R. Rindfuss, Stephen J. Walsh and Vinod Mishra, eds., *People and the Environment: Approaches for Linking Household and Community Surveys to Remote Sensing and GIS.* Boston: Kluwer Academic Publishers. Pp 201-221.

Geist, H. J. and E.F. Lambin. 2002. "Proximate Causes and Underlying Forces of Tropical Deforestation." *BioScience* 52(2):

Geoghegan, J, S.C. Villar, P. Klepeis, P.M. Mendoza, Y. Ogneva-Himmelberger, R.R. Chowdhury, B. Turner and C. Vance. 2001. "Modeling Tropical Deforestation in the Southern Yucatán Peninsular Region: Comparing Survey and Satellite Data." *Agriculture, Ecosystems, and Environment.* 85(1-3): 25-46.

Groves, Robert M. 1989. *Survey Errors and Survey Costs.* New York: Wiley

Groves, Robert M. and Mick P. Couper. 1998. *Nonresponse in Household Interview Surveys.* New York: Wiley.

Hudson, W. D. & Ramm, C. W., 1987. "Correct formulation of the Kappa coefficient of agreement." *Photogrammetric Engineering and Remote Sensing,* 53(4): 421-422.

Klepeis, P. and B. L. Turner II. 2001. "Integrated Land History and Global Change Science: The Example of the Southern Yucatán Peninsular Region Project." *Land Use Policy* 18(1): 272-39.

Laney, R. M. 2002. "Disaggregating Induced Intensification for Land-Change Analysis: A Case Study from Madagascar" *Annals of the Association of American Geographers* 92: 702-26.

Lessler, Judith T. and William D. Kalsbeek. 1992. *Nonsampling Error in Surveys.* New York: John Wiley and Sons.

Liu, Jianguo, Marc A. Linderman, Zhiyun Ouyang, and Li An. 2001. "Ecological Degradation in Protected Areas: The Case of Wolong Nature Reserve for Giant Pandas." *Science.* 292: 98-101.

Liu, Jianguo, Li An, Sandra S. Batie, Richard E. Groop, Zai Liang, Marc A. Linderman, Angela G. Mertig, Zhiyun Ouyang, and Jiaguo Qi. 2003. Human Impacts on Land Cover and Panda Habitat in Wolong Nature Reserve: Linking Ecological, Socioeconomic, Demographic and Behavioral Data." In Jefferson Fox, Ronald R. Rindfuss, Stephen J. Walsh and Vinod Mishra, eds., *People and the Environment: Approaches for Linking Household and Community Surveys to Remote Sensing and GIS.* Boston: Kluwer Academic Publishers. Pp 241-263.

Lutz, W. and E. Holm. 1993. "Mauritius: Population and Land Use." Pp. 98-105 in C. L. Jolly and B.B. Torrey, eds. *Population and Land Use in Developing Countries.* Washington, D.C.: National Academy Press.

Liverman, Dianna, Emilio F. Moran, Ronald R. Rindfuss, and Paul C. Stern, editors. *People and Pixels.* Washington, DC: National Academy Press.

Macleod, R.D. and R.G. Congalton. 1998. "A quantitative comparison of change-detection algorithms for monitoring eelgrass from remotely sensed data." *Photogrametric Engineering and Remote Sensing,* 64(3): 207-216.

Mausel, P., Y. Wu, E. Moran and E. Brondizio. 1993. "Spectral Identification of Succession Stages Following Deforestation in the Amazon." *Geocarto International* 8: 61-72.

McCracken, S., E. Brondizio, D. Nelson, E. Moran, A. Siqueira, and C. Rodriguez-Peraza. 1999. "Remote Sensing and GIS at Farm Property Level: Demography and Deforestation in the Brazilian Amazon." *Photogrammetric Engineering and Remote Sensing* 65(11):1311-1320.

McCracken, S.D., A.D. Siqueira, E, F. Moran and E. S. Brondizio. 2002. "Land Use Patterns on an Agricultural Frontier in Brazil." Pp. 163-192 in C.H. Wood and R. Porro, eds., *Deforestation and Land Use in the Amazon.* Gainsville, FL: University Press of Florida.

McGarigal, K. and Marks, B.J. 1993. *Fragstats: Spatial Pattern Analysis Program for Quantifying Landscape Structure.* Forest Science Department, Oregon State University, Corvallis, Oregon.

Moran, E. F., Brondizio, E.S. and McCracken, S. 2002. "Trajectories of Land Use: Soils, Succession, and Crop Choice." In C. Wood and R. Porro (eds.) *Deforestation and Land Use in the Amazon.* University Press of Florida, Gainesville. Pgs. 193-217.

Moran, E.F. and E. Brondizio. 1998. "Land Use Change after Deforestation in Amazonia." In D. Liverman, E. Moran, R. Rindfuss, and P. Stern (eds.) *People and Pixels: Linking Remote Sensing and Social Science.*. National Academy Press, Washington DC. Pgs. 94-120.

Moran E.F., Brondizio, E.S. 2001. "Human Ecology from Space: Ecological Anthropology engages the study of global environmental change." In M. Lambek and E. Messer. (eds.) *Thinking and Engaging the Whole: Essays on R. Rappaport's Anthropology.* Ann Arbor: University of Michigan Press, Ann Arbor. Pgs. 64-87.

Moran E.F., Brondizio E.S., Mausel P., Yu W. 1994 "Deforestation in Amazonia: Land use change from ground and space level perspective." *Bioscience* 44(5): 329-339.

Moran, E.F., A. Siqueira and E. Brondizio. 2003. "Household Demographic Structure and Its Relationship to Deforestation in the Amazon Basin.." In Jefferson Fox, Ronald R. Rindfuss, Stephen J. Walsh and Vinod Mishra, eds., *People and the Environment: Approaches for Linking Household and Community Surveys to Remote Sensing and GIS.* Boston: Kluwer Academic Publishers. Pp 61-89.

Rindfuss, Ronald R and Paul Stern 1998. "Linking Remote Sensing and Social Science: The Need and the Challenges." Pp. 1-27 in Dianna Liverman, Emilio F. Moran, Ronald R. Rindfuss, and Paul C. Stern, editors. *People and Pixels.* Washington, DC: National Academy Press.

Rindfuss, Ronald R., Stephen J. Walsh, Vinod Mishra, Jefferson Fox and Glenn P. Dolcemascolo. 2003a. "Linking Household and Remotely Sensed Data: Methodological and Practical Problems." In Jefferson Fox, Ronald R. Rindfuss, Stephen J. Walsh and Vinod Mishra, eds., *People and the Environment: Approaches for Linking Household and Community Surveys to Remote Sensing and GIS.* Boston: Kluwer Academic Publishers. Pp 1-30.

Rindfuss, Ronals R., Pramote Prasartkul, Stephen J. Walsh, Barbara Entwisle, Yothin Sawangdee, and John B. Vogler. 2003b. "Household - Parcel Linkages in Nang Rong,Thailand: Challenges of Large Samples." In Jefferson Fox, Ronald R. Rindfuss, Stephen J. Walsh and Vinod Mishra, eds., *People and the Environment: Approaches for Linking Household and Community Surveys to Remote Sensing and GIS.* Boston: Kluwer Academic Publishers. Pp. 131-172.

Robbins, P. 1998. "Authority & Environment: Institutional Landscapes in Rajasthan, India." *The Annals of the Association of American Geographers.* 88(3): 410-435.

Robinson, W.S. 1950. "Ecological Correlations and the Behavior of Individuals." *American Sociological Review.* 15(3): 351-357.

Rosero-Bixby, L. and A. Palloni. 1998. "Population and Deforestation in Costa Rica." *Population and Environment.* 20(2): 149-185.

Seto, K. C. and R. K. Kaufmann. 2003. "Modeling the Drivers of Urban Land Use Change in the Pearl River Delta, China: Integrating Remote Sensing with Socioeconomic Data." *Land Economics.* 79(1):106-121.

Turner, B. L. II, S.C. Villar, D. Foster, J. Geoghegan, E. Keys, P. Klepeis, D. Lawrence, P.M. Mendoza, S. Manson, Y. Ogneva-Himmelberger, A.B. Plotkin, D.P. Salicrup, R.R. Chowdhury, B. Savitsky, L. Schneider, B. Smook, and C. Vance. 2001. "Deforestation in the Southern Yucatán Peninsular Region: An Integrative Approach." *Forest Ecology and Management.* 154 (3):353-370.

Turner, B. L. II, 2002. "Toward Integrated Land-Change Science: Advances in 1.5 Decades of Sustained International Research on Land-Use and Land-Cover Change," in W. Steffen, J. Jäger, D. Carson and C. Bradshaw, eds., *Challenges of a Changing Earth: Proceedings of the Global Change Open Science Conference, Amsterdam, NL, 10-13 July 2000,* Springer-Verlag, Heidelberg, GR., pp. 21-26.

Turner, B. L. II, J. Geoghegan and D. F. Foster 2003 Integrated Land-Change Science and Tropical Deforestation in the Southern Yucatán: Final Frontiers. Clarendon Press of Oxford University Press.

Turner, B. L. II, and J. Geoghegan. 2003. "Land-Cover and Land-Use Change (LCLUC) in the Southern Yucatan Peninsular Region (SYPR): An Integrated Approach." In Jefferson Fox, Ronald R. Rindfuss, Stephen J. Walsh and Vinod Mishra, eds., *People and the Environment: Approaches for Linking Household and Community Surveys to Remote Sensing and GIS.* Boston: Kluwer Academic Publishers. Pp 31-60.

Walsh, Stephen J., Richard E. Bilsborrow, Stephen J. McGregor, Brian G. Frizelle, Joseph P. Messina, William K.T. Pan, Kelley A. Crews-Meyer, Gregory M. Taff, and Francis Baquero. 2003. "Integration of Longitudinal Surveys, Remote Sensing Time Series, and Spatial Analyses: Approaches for Linking People and Place." In Jefferson Fox, Ronald R. Rindfuss, Stephen J. Walsh and Vinod Mishra, eds., *People and the Environment: Approaches for Linking Household and Community Surveys to Remote Sensing and GIS.* Boston: Kluwer Academic Publishers. Pp 91-130.

Walsh, Stephen J., Tom P. Evans, W.F. Welsh, Barbara Entwisle and Ronald R. Rindfuss. 1999. "Scale Dependent Relationships between Population and Environment in Northeast Thailand." *Photogrammetric Engineering and Remote Sensing.* 65(1): 97-105.

Wood, C.H. and D. Skole. 1998. "Linking Satellite, Census, and Survey Data to Study Deforestation in the Brazilian Amazon. Pp. 70-93 in D. Liverman, E.F.Moran, R.R. Rindfuss, and P. Stern, *People and Pixels*. Washington, D.C.: National Academy Press.

ACT Publications 2003

No. 03-01
Moran, E., A. Siqueira and E. Brondizio. "Household Demographic Structure and it's Relationship to Deforestation in the Amazon Basin." *People and the Environment: Approaches to Linking Household and Community Surveys to Remote Sensing and GIS.* J. Fox, V. Mishra, R. Rindfuss, and S. Walsh (eds.) 2003. Kluwer Academic Press. Pp. 1-30.

No 03-02
Batistella, M., S. Robeson, E. Moran. "Settlement Design, Forest Fragmentation, and Landscape Change in Rodonia, Amazonia." *Photogrammetiric Engineering & Remote Sensing* Vol. 69(7), July 2003, pp. 805-812.

No 03-03
Lu, D., P. Mausel, E. Brondizio, E. Moran. "Classification of successional forest stages in the Brazilian Amazon basin." *Forest Ecology and Management* Vol. 181, pp. 301-312. (2003).

No 03-04
Futemma, C., E. Brondizio. "Land Reform and Land-Use Changes in the Lower Amazon: Implications for Agricultural Intensification." *Human Ecology* Vol. 31(3) September 2003. Pp. 369-402.

No 03-05
Siqueira, A., S. McCracken, E. Brondizio, E. Moran. "Women and Work in a Brazilian Agricultural Frontier." In: Gender at Work in Economic Life. Gracia Clark (editor). 2003. Altamira Press, New York, NY. Pp. 243-265.

No 03-06
Hurtt, G.; X. Xiao, M. Keller, M. Palace, G. Asner, R. Braswell Eduardo Brondizio, Scott Hetrick et al. "IKONOS imagery for the Large Scale Biosphere-Atmosphere Experiment in Amazonia (LBA)." ***Remote Sensing of Environment*** 88(2003). Pgs 111-127.

No 03-07
Lu, Densheng; Emilio Moran, and Mateus Batistella. "Linear mixture model applied to Amazonian vegetation classification." *Remote Sensing of Environment* 87(2003). Pgs 456-469.