INTER-AMERICAN INSTITUTE FOR GLOBAL CHANGE RESEARCH

Applying Ecological Knowledge to Landuse Decisions

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Foreword

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In this volume the Inter-American Institute for Global Change Research synthesizes the knowledge and experience of several of its collaborative research networks on terrestrial ecosystems, forests, grasslands, agriculture and river margins, and explores how this may be used to guide decisions on landuse. The analysis (chapters 2-4) shows that there are essentially two distinct ways in which ecological knowledge can influence landuse decisions:
- knowledge of ecosystem function and ecosystem services commonly is used to argue against landuse conversion and for ecosystems conservation to preserve their services.
- knowledge of ecosystem process can be applied to managed lands to develop more resilient, lower input, production systems that use some of the efficiencies which natural selection and adaptation has produced in natural ecosystems.
For example, knowing that wetlands provide flood protection and riparian strips help maintain water quality, preservation of such areas is advocated to maintain these ecosystem services. Knowledge of nutrient cycling mechanisms in natural vegetation can be applied to resource management to emulate these processes, for instance by enhancing nutrient cycling through agroforestry or managing crop residues to provide nutrient release synchronous to crop demands.

Ecosystem conservation

Traditional conservation efforts have emphasized human threats to species. An improved understanding of ecosystem function and services is now shifting attention towards the conservation of entire ecosystems. Demonstrating the links between ecosystem services and underlying ecosystem processes is a useful way to make ecological knowledge relevant to landuse decision making, and to help decision-makers identify components of a landscape that provide essential services which should be preserved. Ecosystem services have been classified by the Millennium Ecosystem Assessment as "supporting" for instance nutrient cycling, "provisioning" products for human use, "regulating" for instance water flows in a landscape, and "cultural" offering attractions or a sense of belonging. All need to be considered in landuse planning.

Beyond landuse decisions based on current sustainability scenarios, resilience in ecosystem services such as the regulation of water resources, control of erosion, preservation of landscapes, ecotones and habitat for wildlife, will also be important in the adaptation to climate change. Landuse planning therefore has to take future scenarios for global change into account.

There is a wealth of information on the consequences of impairing vital ecosystem services as a result of landuse change. These include reduced soil water infiltration rates resulting in floods and erosion, soil organic matter and nutrient loss resulting in reduced fertility and carbon stocks, and loss of vegetation cover which changes evapo-transpiration and local to regional climate regulation. These processes on land affect water resources through

contamination, increased sediment transport and siltation, increased amplitudes of river flow, floods and water shortages.

Examples of impaired ecosystem services in this volume include the Pampas natural grasslands in Argentina and Uruguay (Cruz et al., chapter 18) being planted to forests for cellulose production that lower ground water tables (Coutinho et al., chapter 8), montane forest on the steep eastern slope of the Andes being cleared for cultivation with resulting landslides and nutrient losses (McClain et al., chapter 11), and the Yucatan forests in Mexico being cleared for agriculture and plantations that contaminated honey production (Jimenez et al., chapter 6).

Ecosystem functions and services can to some degree be substituted by management interventions, energy and material inputs. Such interventions include irrigation, nutrient additions, pesticide or herbicide applications, or landscape alterations such as terracing. Agriculture or forestry production pays for the needed substitutions. Substitutions and associated costs can be reduced by maintaining or restoring some ecosystem services. Agroforestry systems for instance can restore nutrient cycling and carbon sequestration lost with the clearing of forests. Agroforestry, crop rotations, mixed cropping and green manuring can also restore biodiversity in an agricultural landscape.

Biodiversity is critical to ecosystem functioning and resilience (Finegan et al., chapter 13), although the functional relationships have often not been demonstrated in sufficient detail to permit strategic biodiversity management in cultural landscapes. In the example of meso-American coffee production (Castellanos et al., chapter 5), conservation of biodiversity also carries benefits related to societal value labels of "organic", "bird- friendly", or even "fair-trade" which are partly related to ecological concerns.

Ecosystem services are used to different degrees by different sections of society. Reduced access to forest products (timber, fuel wood, medicines and honey) as a result of landuse change to agriculture may affect other social groups than those benefiting directly from the agricultural use. Alterations in functional biodiversity therefore lead to differential benefits and vulnerabilities for different stakeholders, both locally and remotely. This is an important emerging issue about which there is very little conceptual or empirical work. Chapter 9 by Cáceres et al. establishes a common and typical link between ecosystem preservation and poverty: small-holder production systems that are not integrated into the agro-industrial chain, and follow subsistence objectives with minimum external inputs are labeled "agro-ecological". This highlights the tension between ecological conservation and societal aspirations.

The context of development and ecosystem sustainability was explored in detail in chapters 6 and 16 by Jimenez et al. In order to implement ecological landuse planning in rural communities in Yucatan, the authors evaluated natural resource availability and sustainability, productivity and environmental impact of productive systems, living standards, social equity, and social agreements. Once a proposal for a landuse plan was validated at municipal level, institutions were coordinated for implementation, followed by an environmental log of actions and impacts. Traditional knowledge of Maya farmers on soils was used as one of the inputs to ecological landuse planning. Contemporary multiple-use strategies by the Maya show low production per landuse unit, but relatively high production of the aggregate landscape. Farmers have evolved a dynamic permanent system based on the benefits of diversity. This multiple-use strategy copes with the landscape variety, soil, vegetation and management history, and provides a base for the ecological landuse plans. Supporting development beyond traditional uses and knowledge, ecological landuse planning has become necessary to improve productivity and reduce poverty while sustaining the natural resource base. The use of traditional knowledge

clearly has its limitations under changing environmental conditions and in the context of innovation. Traditional knowledge may also not be complete and is not always based on fact.

Interventions towards improved land management, organic agriculture, honey production, rural tourism and handicraft production, recovery of degraded grasslands, fire management etc. face a 'trade-off' between natural resource sustainability and poverty reduction. Often, the more a program focuses on poverty alleviation, the more difficult it is to achieve natural resource sustainability. A more viable alternative is to include off-farm and non- agricultural activities in rural development projects (Rodríguez-Bilella and Tapella, chapter 7). Consideration of both natural and human capital is critical to the success of land management interventions to maintain ecosystem functioning and to meet the needs and aspirations of populations.

In Meso-America, the greatest amount of biodiversity for many groups of organisms has been recorded outside protected areas in regions inhabited, used, and modified by traditional cultures and land users. Such areas constitute an ecological mosaic that may include a wide diversity of ecosystems such as secondary forest, slash and burn agriculture home gardens, plantations and pastures. The landscape patterns of agroforestry, for example, may serve as connective or even home range habitat for wild species. Integration of agroforestry lands into regional biodiversity planning to provide conduits between reserves could protect large numbers of species in the long-term.

Understanding the socio-economic underpinning of restoration/conservation and agriculture/silviculture provides insight into how to manipulate incentives to optimize both biodiversity and individual and local economic well-being.

Selective conservation

High fertility riparian soils in the Amazon support more valuable protein-rich crops than adjacent upland soils (McClain et al., chapter 11). On the other hand riparian zones are critical for the protection of river water quality. Effective management of riparian zones requires knowledge of ecosystem function and connectivity, and a fine balance between use and conservation. Management plans must integrate terrestrial production and aquatic protection, and must be acceptable to the inhabitants of the region who may not value the protective function of riparian zones. The task of science education is to link the experience of a lack of water for human and animal consumption in the dry season and an increase in floods during the rainy season to the degradation of riparian strips. Ecology, forestry and agronomy knowledge must therefore be combined to provide guidance for the designation of areas of permanent protection along river margins, on steep slopes and around springs.

Ecologists have shown the harmful effects of forest fragmentation in the pioneering fronts. Although many Amazonian farms maintain significant areas under native forest, counteracting the effects of fragmentation will need management and public policy on a more regional scale to maintain important ecosystem functions (Tourrand et al. chapter 12).

Land cover change occurs as a result of both human and natural factors, and both may interact in complex ways. Throughout the Holocene the montane forest belt of the tropical Andes and the páramo at higher elevations, have reacted to climate change by upward extension of the forest under warmer conditions and the downward advance of the páramo under colder conditions (Sarmiento and Pinillos, chapter 14). In the Northern Andes, the upper limit of crops may reach ca. 3800 m above sea level, roughly coinciding with the 5°C isotherm. Below this limit, the spatial arrangement of crops and secondary succession after cropping follow climate and terrain

patterns such as frost frequency, insolation, aspect, slope and elevation. Isolated forest patches well above the continuous forest line may therefore be due to human action (deforestation) natural factors. Similar arguments exist to explain the forest-savannah interfaces, which may be due to climate, soils or past human action (fires and deforestation).

Costa Rica shows a cycle of deforestation - forest reestablishment because of changing economic conditions and regulation (Calvo-Alvarado et al., chapter 15). Initially governments encouraged colonization and deforestation, mainly for cattle production. Later, the realization of the value of ecosystem services, ecotourism, and unstable agricultural commodity markets shifted the emphasis towards conservation. This coincides with the Amazonian observation of chaotic deforestation in the initial settlement phase followed by a more orderly and possibly conservative and restorative phase.

Ecological knowledge and land management

To apply ecological knowledge from native to agricultural systems provides opportunities for optimizing resource use. Transferring models of nutrient and carbon fluxes developed in natural ecosystems helps optimize flows in managed systems. Based on nutrient budgeting, Salcedo and Menezes (chapter 10) report from NE Brazil that after three years of cropping, nitrogen and phosphorus removal from the top layer of farmers' fields amounted to 7% and 3% of total soil N and P respectively. Erosion losses between were similar to 10 times greater depending on exposure to rainfall. This points to the need for adequate residue management, mixed cropping and permanent cultures that minimize nutrient and soil losses. If combined with judicious inputs aiming at alleviating critical resource limitations that may provide considerable yield advantages. For instance increasing planting density to intercept a maximum of water and raising soil P availability led to a 10-fold increase in biomass production per mm of rainfall.

Applying knowledge of the below and above-ground biodiversity and resilience of natural grasslands, Hamel et al. (chapter 17) identify potential benefits to ecosystem function of increasing the number of plant species in Canadian grazing lands. Among ranchers, the authors find a profound understanding of the grassland ecosystem that supports them, they "know the land." This knowledge is mainly derived from long-term anecdotal evidence, often over generations. Decisions to retain the native prairie landscape are often based on topography, soil textures, local climate, forage potential and lifestyle.

In experiments that aim to restore the resilience of native prairie to planted pastures, inter- and intra- species competition increased as available resources are depleted. This caused a more complete exploration of the soil. Plant mixtures may, in the future, yield more than monocultures as a result of better resource exploration, due to different rooting depth patterns and resource exploration. This is also the basis of overyielding seen in tropical intercropping and in the yield advantages seen in well managed and adapted agroforestry systems.

Communicating the science of landuse

Scientists must continue to increase knowledge but should also make their knowledge available and relevant to decision makers. This requires data reduction to manageable information.

Assessments of current and future outcomes must be designed to synthesize patterns arising from environmental change and policy. Without the use of indicator based assessments, the size of the data and information flows becomes overwhelming for the decision process. Such synthesis necessarily will have to be done across disciplines and societal sectors, which goes beyond the traditional scientific publication and communication that lends itself to established peer review processes. In order to contribute to decision-making on global change issues, ecological knowledge must therefore be validated by a larger circle of peers, and discussed within broad circles of stakeholders, in the light of their own perceptions and experience. This volume is a contribution to that process.

2.
Making ecological knowledge relevant for land-use decision makers.

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In the past 50 years, land use knowledge, ecosystem science, ecosystem services, and technology have had a central role in securing global food security, by increasing productivity at a faster pace than population growth. This apparent success has not resulted in poverty reduction for all land users and has not necessarily led to good land management. A large number of environmental processes with negative effects have modified ecosystems under inappropriate land management. Not only must this damage be repaired, but further damaging processes need to be avoided. This poses an immense challenge to all stakeholders and societies.

Ecological functions and services will have to sustain the world population. Food security and demand for wood products for growing populations will remain a challenge in the next few decades, especially under climatic and environmental global change. So too will the task of transmitting ecological and management knowledge to land-users and governments with very different financial resources. Ecosystem functions and services will be important in the adaptation to climate change, regulating water resources and controlling erosion, preserving landscapes, conserving ecotones and providing habitat for wildlife (Cruz et al., chapter 18, this volume). Governments are responding to public pressure to preserve ecological biodiversity (e.g. UN convention on biodiversity) and set aside more native ecosystems, forests and grasslands for controlled access and use, and develop new scenarios whereby land users will attempt to preserve ecosystem services important for human wellbeing in the longer term (Daily 1997).

To cope with the demands of these changes, scientists at all levels face challenges in communicating results to policy makers, other stakeholders and the public at large. Science and policy-making are not linear processes that question, analyze, and propose solutions: they are both complex non-linear iterative processes that deal with multiple, interlinked, and changing questions. Closer cooperation between scientists and decision-makers is desirable but difficult to achieve. Despite the difficulties in this process, it is essential that scientists embrace the challenge, change, and improve their interaction and communication with decision makers. Scientists must continue to increase knowledge but should also make their knowledge available and relevant to decision makers. Land use decisions will continue to be made by others - however scientific understanding of ecological processes and their changes in a global environment is so important to future land sustainability that it must be communicated clearly and early in order to be understood and taken into account by decision makers.

The wide variety of land-use change situations studied by Collaborative Research Networks (CRN) and related projects provides a unique opportunity to reflect on the effective communication of ecological knowledge to land-use decision makers. Building on the CRN experience, this chapter describes how a working dialogue can be developed

with land-use decision makers from farmers to governments - and in very different social, economic and ecological contexts.

Ecological knowledge for land use decision making

Natural resource management has been largely based on traditional ecological knowledge and knowledge conveyed through agricultural extension services. Ecological knowledge is one of the many components of land-use decision making, together with economic, social and political considerations. Scientists play a key role in generating this knowledge and making it available, directly or indirectly to decision makers.

Scientific knowledge building and the subsequent development of user-applications occur within a system involving many actors including scientists, professionals, IT specialists, librarians, communicators and the end-users of scientific knowledge and its applications. Ecological knowledge, like other types of scientific knowledge, grows through the addition of new information to a general knowledge pool. Growth of scientific knowledge depends largely on the accumulation and organization of information produced by experimental or descriptive research and monitoring activities. Surveys may compile traditional forms of knowledge into information systems for information handling, forecasting or modelling. Scientific progress is highly dependant on open access to existing knowledge by scientists who contribute to this body of knowledge. Scientists are knowledgeable and familiar with searching for and working with information, and can play a central role in information flows out of the pool of ecological knowledge into land use decision making.

Involving specialist intermediaries in communicating ecological knowledge

Direct dialogue between scientists and decision makers accelerates the adjustment of land-use, especially when rapidly changing environmental (e.g., climatic) or socio-economic conditions require a rapid response. However, intermediaries are often needed to make scientific knowledge legitimate to a target audience, and feeding information to them may be the most appropriate way scientists can contribute to the dissemination of ecological knowledge. Agricultural extension specialists are a well-known example of specialized intermediates that translate scientific knowledge into relevant, credible and legitimate information that will more effectively reach the target audience (Cash et al. 2003). For the same reasons, other intermediaries such as NGOs and key community members should also be involved in the communication process.

Communication using indicators

Holling (1998) identified "two cultures in ecology". He compared an "analytic approach" that develops its activity by expanding the existing knowledge base through experiments, with an "integrative approach" where progress is achieved through the integration of existing knowledge, from different disciplines. The integration of knowledge in programs

such as the Millennium Ecosystem Assessment has been very successful in addressing a broad range of issues using scenarios, modelling and a key indicators.

Politicians and land users alike prefer to use relevant indicators of ecological conditions that are easy to use and highly descriptive. For instance, meteorological services issue daily public reports on UV radiation strength on a scale of 1 to 10. These are easy to understand and have been widely adopted by the public at large. Erosion indices have been used successfully for landscapes management. Land health and stability can be assessed through long term monitoring of ecosystem properties using indicators. Long term monitoring can answer questions related to ecological stability. For instance, Long Term Ecological Research (LTER) Projects , although costly, reach out to the broader scientific community, natural resource managers, policymakers, and the general public by providing decision support, information, recommendations and the knowledge and capability to address complex environmental challenges. However, it is essential that LTER projects develop useful indicators.

Indicators allow an expanding set of sentinel observations to be drawn into policy-making. As new knowledge becomes available or the focus of decision-making shifts, underpinning data flows can be augmented or replaced. Indicators can be descriptive, relate to performance, efficiency, policy-effectiveness or overall welfare, but in the context of sustainability it is their integration across different policy arenas that are most critical. These sophisticated combinations of data in the form of assessments of current and future outcomes enable specific patterns arising from different policy interactions to be differentiated. Without the use of indicator based assessments, the size of the data and information flows becomes overwhelming (Hák et al. 2007).

Enlarging the circle of peers

Within the scientific community, research results are routinely evaluated through a peer-review process. Research articles are reviewed by two or three experts in the field before becoming part of the body of approved scientific literature. However, the stakes have changed as environmental issues from local to global scales are now relevant to an increasing number and variety of stakeholders. Complex issues such as global environmental change face considerable uncertainty as well as high social relevance (or stakes) (Figure 2.1). In order to contribute to decision-making on these issues, ecological knowledge must therefore be validated by a larger circle of peers.

To become relevant, ecological knowledge must be communicated and discussed within broad circles of stakeholders, under the light of their own perceptions and experience (Figure 2.1). Through this process, stakeholders get involved in qualifying ecological knowledge for informed decision making (Funtowicz and Ravetz, 1993). By involving them, stakeholders can decide how to incorporate ecological knowledge in their decision process.
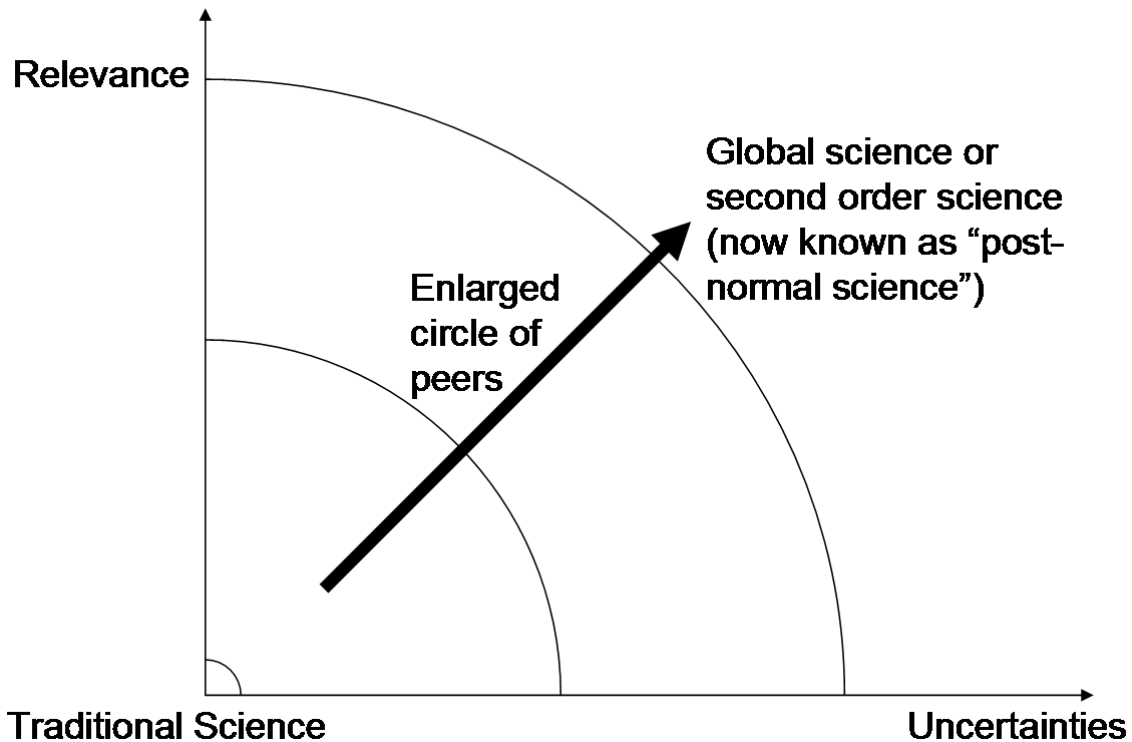
Figure 2.1: Effective scientific communication means enlarging the circle of peers involved in the research (Adapted from Funtowicz and Ravetz, 1993)

Making ecological knowledge relevant requires an understanding of the decision making process (Checkland & Holwell, 1998; Lynam & Stafford-Smith, 2003). Science must feed decision making systems with high quality information that is designed to inform non-specialists rapidly and effectively. This requires developing an explicit model of the decision making process itself, which can only be achieved through a multidisciplinary approach to land-use change (Tourrand et al., chapter 12 and Ojima et al. chapter 3, both this volume) and a dialogue between scientists and decision makers.

Communicating ecological knowledge through dialogue

Research projects are commonly designed within academic institutions, with no input from wider society or land-use decision makers. This might be called supply-driven research (scientist supply research questions and results – see Figure 2.2). Knowledge generated by this approach is often not directly or immediately relevant for the targeted audience, although it feeds the broader pool of scientific knowledge. Consequently, research results from these projects are often irrelevant to decision making.

Alternatively, some research projects involve stakeholders in the project design (also see: appendix 2.1). A research question that was formulated on the basis of stakeholder understanding of the issues at hand is more likely to generate results that can be easily communicated back, using the same understanding. This can be called demand-

driven research (Figure 2.2). However, such projects often bring little new information and ignore research avenues with high potential immediate impacts.

Engaging research scientists and decision makers in a dialogue

Research projects that wish to make ecological knowledge both relevant and available to land-use decision makers need to strike a balance between supply-driven new issues and knowledge, and demand-driven relevancy to stakeholder concerns. This requires engaging in a continuous dialogue that will progressively generate new research questions and enrich decision-makers understanding of the ecological processes considered.

Scientists formulate the research question and present results…

| Scientists | Research projects | Knowledge results | Target audience:
-NGO
- Financial institutions
- Government
- Extension services
- Farmers
- People |

Scientists dialogue with stakeholders in formulating research questions
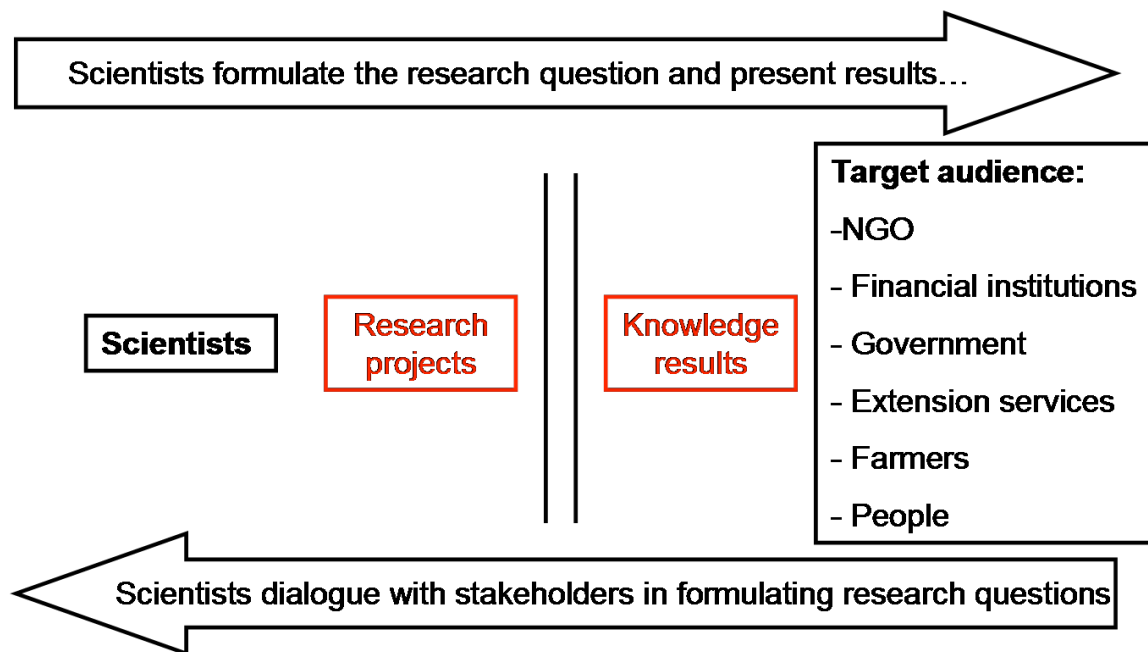
Figure 2.2: Two extremes in research project design. The upper arrow represents supply-driven research and the lower arrow, demand-driven research

Many CRNs and related projects presented in this volume and elsewhere (Tiessen et al. 2007) have engaged in such a dialogue, either in the formulation of their research questions, or during their implementation. For example, in the "Agroecosystem functioning and management in semi-arid Northeastern Brazil" project (Salcedo and Menezes, chapter 10, this volume), scientists based their insertion into the local social networks on a local NGO: Assessoria e Serviços a Projetos em Agricultura Alternativa (ASPTA) that had been involved for many years in rural development issues in the area. ASPTA was already trusted by local farmers, which made its involvement in the formulation of relevant research topics possible. ASPTA and farmers expected the CRN project to answer management questions that required the design of a rigorous scientific experiment.

Using scientific tools for communication

Cash et al. (2003) proposed methodologies and tools for linking science and decision making by facilitating collective action in a common forum. Among these approaches and methodologies, multi-agent systems (MAS) are especially suited to simulate the interactions of society with its environment at different geographical, spatial and social scales.

The CRN project described in Tourrand et al. (chapter 12, this volume) has developed MAS models to understand land-use dynamics in Amazonia. MAS are able to model many entities interacting among themselves and with an external environment. They are an alternative to classical equilibrium models in situations where emergent properties have to be explored, where system components are very heterogeneous (e.g., coupled ecological and social systems), or where spatial-explicitness is essential. Such models can be coupled with easy-to-grasp diagrams to support stakeholder debates, thus promoting collective action (as suggested by the Soft System Methodology – Checkland, 1999). Diagrams themselves are an important and effective tool for scientific communication (Larkin and Simon, 1987). They can be used to organize knowledge, support dialogue and help construct a common understanding of the issues at hand (Lambin and Geist, 2006; Le Page and Bommel, 2006). More generally, scientific tools and models can help effective communication if they are constructed using participatory methodologies, involving stakeholders and decision makers.

Formal participatory methodologies

Stakeholder participation is increasingly considered critical for both the effectiveness of research projects and the usefulness of their findings and policy implications. It can be defined as a process through which stakeholders influence and - in some cases - share control over the research initiatives that might affect them. Participation can take different forms, ranging from information sharing and various consultation methods, to mechanisms for collaboration and empowerment that give stakeholders more influence and control. Participating stakeholders can develop a sense of ownership of and responsibility for the research initiative and take part in deciding what issues might be important and relevant in any research project. Stakeholders can be individuals, groups or institutions such as local governments, directly affected land user groups (e.g., water consortium), indirectly affected groups (e.g., consumer organizations), NGOs dealing with land-use and environmental problems, civil society and private sector organizations.

Different methodologies, strategies and techniques have been tried to identify local stakeholders and promote their participation during field research projects. Each participatory approach is considered suitable for a specific type of situation, in relation to the types of contributions it aims to generate. Some of the earliest approaches are: Participatory Rural Appraisal (PRA, see Chambers, 1994a, 1994b); Participatory Action Research (PAR, see Fals Borda, 1998, and Rahman, 1993), Rapid Appraisal of Agricultural Knowledge Systems (RAAKS, see Engel, 1995); Participatory Technology Development (PTD, see Jiggins and de Zeeuw, 1992; and Farmer Participatory Research (FPR, see Okali et al, 1994). A detailed review of the different participatory approaches is

outside the scope of this chapter but the corresponding literature can be found in appendix 2.2.

In spite of important differences between the various methodologies used to involve stakeholders, they all have in common that the research itself and the involvement of stakeholders are integrated as parts of one unique process. Since the late nineties, new approaches have been developed and documented. These include the Actor Oriented Approach (AOA, see Long, 2001) and the Sustainable Livelihood Approach (SLA, see Moser, 1998, Scoones, 1998, and Bebbington, 2004). In Castellanos et al. and Coutinho et al. (respectively, chapters 5 and 8, this volume) the conceptual bases of these approaches are described in case studies illustrating how stakeholders can be involved and how the land use decision process can be understood using the conceptual ecosystem services framework.

Making ecological knowledge relevant, credible and legitimate

Funtowicz and Ravetz (1990; 1993) discussed how science can influence political decisions. More recently, Cash et al. (2003) have reviewed how scientific activities can be linked with decision making and action. In doing so, they have again identified some necessary attributes of scientific knowledge to have effective impact: Ecological knowledge must be salient, credible and legitimate.

The general conclusions of Funtowicz and Ravetz (1990, 1993) and Cash et al. (2003) can also be applied to on-farm decision making. Scientific knowledge can be effectively communicated during its development and through packaging into tools such as modelling, scenario-based simulations, data banks, computerized decision making tools and maps. The nature and packaging of scientific knowledge are important in order for research results to be usable by decision makers.

Relevant ecological knowledge

As demonstrated in chapters 3 and 4 (this volume) as well as Finegan et al. (chapter 13, this volume), people are dependent on a suite of ecosystem services provided by land under various degrees of management. Demonstrating the link between ecosystem services and key underlying ecosystem functions or processes is a useful way to make knowledge relevant to land-use decision making. This approach has been successfully used by the Millennium Ecosystem Assessment.

Many CRNs have also used the ecosystem service concept to convey the importance of their research findings, thereby making them relevant to concerned land-use decision makers. The "Land use and cover in riparian areas of the Andean Amazon: Consequences for people and ecosystems" project (McClain et al., chapter 11, this volume) examined the hydrological processes that affect the maintenance of soil fertility that rural communities themselves recognize as essential ecosystem services.

Making knowledge credible

Scientists must be rigorous and knowledgeable to be considered as a credible source of knowledge. However, their credibility is not only based on their quality as scientists, but also depends on the quality of the dialogue between them and stakeholders. Credible scientists are open minded individuals developing a relationship based on mutual respect and trust with decision makers. Understanding the land-use decision making process is essential for this. Building trust requires time, an initial investment that serves to build long-lasting credibility. Of course, as in scientific collaboration, delivering promised outcomes to stakeholders is essential to building and maintaining trust. This also allows timely feed-back for keeping research projects on track. Decision makers are well-able to take ecological uncertainties into account and these must be made transparent to decision makers. In case of failure, the sharing of responsibilities in taking into account uncertainties will better preserve the trust between scientists and decision makers.
The reputation of institutions also influences the credibility of their scientists. Policy makers will engage in a dialogue with scientists from reputable institutions. The reputation of a researcher's institution is much less important for land-use decision makers such as farmers, for who the importance of direct personal interactions dominate.

Legitimacy of ecological knowledge

The involvement of institutions in land-use issues (i.e. within national governmental spheres) raises the question of their legitimacy, and with that the legitimacy of the knowledge it generates. Scientists should be careful when engaging with stakeholders and land-use decision makers: crossing the fine line between engagement and advocacy, when not explicit, can result in a loss of legitimacy. Engagement however, remains essential for ecological knowledge to become legitimate, as well as relevant and credible to land use decision makers.

Conclusions

Although ecosystem scientists have already made important and substantial progress in understanding the interactions of global change and land use, it is obvious that this progress is not going to be enough in the immediate future. Ecosystem scientists have learned to adopt a team approach and break down some of the discipline barriers within ecological science. Teams (earth, atmosphere, water and related scientists) are working together to understand the major ecosystems of the world (e.g. Amazon and Parana river basins) and they have made significant progress. But understanding the system is only the first step towards sustainability and, in isolation, it does not immediately produce land use options that can be implemented. Unless these scientists produce relevant, credible and legitimate information for decision makers influencing land use in a given region, they risk being sidelined to academic and research institutions and made irrelevant to land-use decision making. This would be extremely unfortunate as these are the people with valuable knowledge of the ecosystem and their expertise should be available to

decision makers. Earth system science has to develop the skills and connection with the social sciences and with non-scientists like policy and media specialists.

Funding agencies and institutions have been slow to evaluate and fund research projects that propose to bring science and policy teams together. Those that do so have major obstacles to overcome. IAI is one such institution that has understood the importance of this approach and through its CRN projects is funding and attempting to learn how to accomplish this goal. This chapter draws on the experience of those currently working on these problems and provides some recommendations that should help bridge the gap. However, this interaction between scientists and decision makers is still in its infancy and it would be prudent to reassess progress at regular intervals.

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Appendix 2.1: Key questions for a starting research projects

Our analysis of the CRN experience in communicating ecological knowledge to land-use decision makers has given us the opportunity to list a set of key questions that project leaders should contemplate when designing a research project.

- Identify the target audiences
1. Who are the decision makers that might be interested in the project findings and its research question?
2. Will land-use decision-makers be include in the research proposal or research plan?
3. Who is going to lose or gain from the information the project will generate?

- Make scientific information available
4. How will you communicate results to the target audiences?
5. How could you translate the main hypotheses into key statements?

- Identify relevant information
6. Will you involve target audiences from the on-set of the project?
7. If so, will you do so informally or do you plan to use a formal methodology?
8. How will you evaluate if project findings addressed the concerns of the different audiences and impacted their decision making process?

- Make results credible
9. What level of abstraction and synthesis of results will you use in communicating results to each one of the audiences?
10. How do you plan to include an evaluation of certainty/uncertainty in the presentation of results?

- Making conclusions and recommendations legitimate
11. Do you plan to engage research results in the decision making process in spite of their uncertainty?
12. Do you plan to transform your engagement into advocacy?

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3.

Shared functions and constraints of natural and managed systems: implications for human well-being in a changing environment

Bryan Finegan (rapporteur), Dennis Ojima (chair), Jorge Lozanoff, Romulo Menezes, Elke Noellemeyer, Marcela Pinillos, Ignacio Salcedo, and Guillermo Sarmiento

Problem statement

Over the centuries, agriculture has been introduced in environments associated with poor soils, lack of water, and low biodiversity. As a means of managing these challenging environments, agricultural practices harnessed existing ecosystem services and introduced management which augmented these services. However during the past 50 years, the introduction of mechanized methods of land clearing and intensive agricultural practices has provided a means to rapidly modify landscapes and affect the delivery and maintenance of key ecosystem services. These new technologies have provided increased productivity but at the costs of increasing the need to maintain inputs into the system to offset the decline in ecosystem services. They have also led to degradation of ecosystem services, such as soil fertility, water regulation, disease and pest control, and biodiversity.

Natural and managed ecosystems share basic functions (e.g., photosynthesis, evapo-transpiration, nitrogen fixation, herbivory) and constraints (e.g., nutrient and water limitations, pests, erosive slopes). Under land use change, consideration of natural and human capital is critical to the success of land management interventions to maintain ecosystem functioning and to meet the needs of stakeholder communities. In transitions from natural to more managed lands, key ecosystem functions and services are often substituted and subsidized through management interventions. Such interventions include biotic replacements, irrigation, nutrient additions, pesticide or herbicide applications, or landscape alterations (e.g., terracing, land clearing, etc.).

These land use transformations often affect ecosystem functioning in ways that degrade land and ecosystem services. For instance, conversion of grasslands to cropland may accelerate soil organic matter decomposition and nitrogen availability for a number of years, but in the long-term exhausts soil organic matter and nutrients so that water holding capacity and nutrient supply are diminished. These diminished ecosystem services would need to be augmented by addition of water or nutrients to support productivity.

Constraints to land use are not always biophysical. In many situations there are economic, socio-cultural, and political constraints to overcome towards the multiple goals land use. In regions with high levels of biophysical constraints, there is a need for continued human-derived inputs at high economic and energetic costs. The cost associated with overcoming these constraints influences the choice of agricultural system which needs to "pay" for needed inputs. In environments with limited ecosystem services, socio-economic constraints may not permit investment in intensive management; land use may lead to further reduction in ecosystem services, environmental degradation, poverty

and land abandonment. Therefore, developing a system level understanding of biophysical and socio-economic constraints to land use management helps selecting alternatives of "best management" options.

Knowledge of ecosystem services required for different land use systems and of needed management interventions is needed to assess potential opportunities and vulnerabilities of land use management options. In a period of rapid changes in socio-economic and climatic conditions, this information and knowledge is useful to forecast implications of global change (e.g., the rates of changing ecosystem goods and services) and the likely success and failure of land use systems undergoing changes or adapting to changes. In addition, this information will be helpful to identify vulnerabilities of natural and managed systems.

Knowledge of shared functions and constraints of natural and managed systems can help develop better long-term management and agricultural practices. Ecological knowledge is needed to design ways in which ecosystem services are augmented or substituted by management activities under various land uses. Can vital ecosystem functions be maintained along a gradient of increasing human intervention? What is the role of the replacement or subsidization of natural capital by technological inputs or management practices in this process, and how can economic gain and sustainable land use be combined? How do ecological and social systems respond to loss of critical ecosystem services, and how do these responses affect the quality or availability of ecosystem services? In this chapter, we describe initiatives to determine the impacts of human modification of forest landscapes and extractive use of tropical forest on forest functional composition and diversity and therefore the provision of ecosystem services. We then discuss the ecosystemic implications of two emerging land-use change trends: the projected massive increase of biofuel production, and the afforestation of tropical, subtropical and temperate grasslands. This analysis provides insight into how managers, decision makers, and researchers may communicate and share their knowledge and perceptions to understand the inherent constraints within a region and the potential opportunities or risks under changing environmental and socio-economic conditions.

Context

The transition of ecosystems from natural to managed needs to be considered within a landscape context due to the mutual dependence of ecosystem functions and landscapes, as ecosystem services often transcend ecosystem boundaries. For instance, water availability is determined by watershed structure; nutrient availability can be modified by inputs from grazing animals utilizing various landscape elements or by atmospheric or aquatic inputs or losses in the landscape or region. Biotic interactions involve landscape utilization in both space and time, depending on seasonal needs and resource availability within a landscape and ecosystem. These landscape relationships then define the extent to which a particular land use system can be implemented and be successful. Ecosystems are distributed within landscapes and provide different ecosystem services over time. This provides spatial and temporal buffering within the landscape and reduces the vulnerability to a range of environmental perturbations. However, disturbances such as

drought, fires, deforestation or N-deposition may act across ecosystem boundaries across whole landscapes.

The combined effects of climate, soils, biota and disturbances across a landscape define the environmental limits or constraints of the ecosystems occupying a landscape. Various attributes of the landscape, such as slope, aspect, soils, spatial heterogeneity, etc define the particular constraints to water flow and availability, biogeochemical cycles, and biotic interactions. These basic limits often serve as strong determinants to how extensively humans can extract resources and ecosystem services from particular ecosystems or landscapes. Seasonal patterns of temperature and precipitation define the climatic regime for organisms and the timing of biotic processes and their interactions. Changes in the intensity or frequency of precipitation or temperature extremes affect soil erosion, gully formation or fires. The current rate of land use change in many regions of the world is being affected by biophysical changes (e.g., climate warming, drought, storms) and concurrent increased human pressures resulting from increased populations and consumption rates. Globalization has enhanced the availability of information and resources, but has also resulted in the increased ability to extract resources from one region for use in another. This has accelerated the rate of land use intensification, created new markets for goods and services, and modified social, market, and cultural conditions in the Americas. These changes alter the development pathways social-economic conditions and of developing regions. Winners and losers are being redefined depending on their ability to take advantage of socio-economic opportunities and to capture resources within the constraints of their environmental situation.

Land managers are astute observers of environmental and socio-economic conditions. They adapt to changes in both the environment and the socio-economic sectors in order to stay in business from year to year. This awareness is often under-utilized in development and application of new land management schemes. Local managers and operators utilize knowledge from various sources, including environmental knowledge. Recent surveys in the Pampas region of Argentina found that the majority of farmers perceived that climate was changing and were looking for ways to adapt to these changes. The adaptations were aimed to reduce the drought effects resulting from perceived warmer temperatures and decline in precipitation (Cap and Lozanoff, 2006, Lanfranco and Lozanoff 2006). The major constraint related to adaptation was not the lack of knowledge of what to do, but having the resources to make the changes in a timely fashion.

Case studies, outstanding and emerging issues

Several IAI projects carried out in the last decade can provide greater specificity to the general consideration of land use effects on ecosystem services and associated functions we consider. Land use change in vast areas of Central and South America has destroyed, fragmented, and simplified natural habitats and turned the landscapes of many regions into uniformly cropped agricultural land. Large scale agricultural intensification has brought about a complete loss of diversity not only at the field scale but also across landscapes. This loss of diversity also implies the lack of diversification at the farm and regional economical scale. While the loss of biodiversity jeopardizes ecosystem

functioning and resilience, the lack of diversification also creates high economical risk since regional and farm economies depend on only one commodity, its price and market behavior. The destruction of the mosaic that landscapes require for sustainability and the lack of site-specific management will lead to strong differences in degradation processes, creating new interactions within the landscape and affect farm incomes.

Case study 1. Ecosystems functions after land use change in low input, subsistence system in semi-arid NE Brazil: constraints and management alternatives

The native vegetation of semi-arid NE Brazil, a dry deciduous forest known as caatinga, presents high taxonomic and functional diversity and is dominated primarily by tree species (see Salcedo and Menezes, chapter 10, this volume). In this region, agricultural development has been restricted to shifting cultivation of maize, beans, and pastures. Limited permanent cropping is feasible in valleys, montane areas, and transition zones with more water resources. The replacement of caatinga by crops and pasture reduces both taxonomic and functional biodiversity and causes a great loss in soil quality.

The loss of ecosystem services, such as nutrient and water cycling, biodiversity, control of erosion, and soil, loss cannot be compensated by management interventions since most of the population lives below the poverty level. The supply of nutrients and water for biomass production has to rely primarily on ecosystem processes, which poses great challenges to management.

As a management alternative, agroforestry systems were capable of performing, at least partially, some of the ecosystem functions lost with the removal of the caatinga. Land use practices that preserved native trees or introduced tree species within agricultural fields and pastures increased biomass productivity and improved water use. Green manures are more efficient organic fertilizers, and taking into consideration the synchronization between nitrogen mineralization and crop demand also increased crop yields. Vegetation strips planted on contour reduced erosion losses of soil, organic matter, nutrients and water. These management interventions represent low-cost, low-input alternatives to replace ecosystem services lost with the removal of the native vegetation. As such, they improve the quality of life of farmers, while helping to preserve the soil and the native biodiversity.

Case Study 2. Land use and ecosystem functions in a climatic gradient across the Argentinean Pampa

Along the climatic gradient of the Pampas existed temperate grasslands in the more humid (900 mm annual precipitation) regions and temperate savannahs in the semiarid areas (<400 mm precipitation). Present production systems are typically market oriented commodity production with negligible value-added processing of products. There is ample access to technology and to professional advice either through government extension or private consultants. The grassland and the savanna ecosystems were initially converted to rangelands based on natural grasses and subsequently turned into rotation systems of cash crops and perennial pasture livestock production, while the more arid

western areas conserved natural savannah vegetation and are used for extensive livestock production. These systems have been able to operate on the inherent availability of ecosystem services with almost no external fertilizer inputs and with only slight modifications of carbon and nutrient balances.

Recent trends include a transition to a more capital-intensive oilseed cropping. The transformations towards more intensive cropping in the more arid portion of the region have not increased crop productivity to the same extent as in the sub-humid regions. Although fertilization would support these cropping systems in the more humid region, losses of soil organic matter are observed. To overcome this, cover crops and residue management are needed to augment the organic matter input to maintain soil physical and fertility properties for crop production. In the drier regions, cropping systems are constrained by the lack of soil moisture. Therefore increasing productivity through fertilizer inputs is only feasible in deep, loamy soils, and after receiving sufficient rainfall during fallow.

While intensive land use with a high levels of external inputs can be sustainable in environments that have few constraints, in more constrained environments intensification does not lead to higher productivity. On the contrary, they can cause degradation of ecosystem services and a loss of the soil's productive capacity. Substitution of ecosystem functions related to nutrient cycles can augment soil fertility, and in addition, addition of soil organic matter can reduce degradation of soil properties in certain environments. In environments that are extremely constrained by water availability, technological input cannot substitute key ecosystem functions.

Case Study 3. Tropical savanna and replacement by high-input soybean cultivation

Tropical savannas occur under warm, semi-arid climate, and often on low fertility soils (Sarmiento 1984). Two main environmental constraints to animal husbandry are the long dry season (> 4 months) and the poor nutrient availability (Sarmiento 1984, Sarmiento and Pinillos 1999). Extensive animal husbandry evolved in response to the environmental stressors in a way that survived for about three centuries. Since the mid 20th century, though, a land-use intensification has taken place with the initial introduction of improved pastures and livestock, followed more recently the introduction of intensive annual cropping systems. The establishment of the soybean system is the culmination of this historical trend and it is expected to cover most the Cerrado region. The soybean system on oxisols increasingly depends on irrigation, liming to correct soil acidity, heavy inputs of fertilizer, intensive use of agro-chemicals, and the introduction of genetically-modified cultivars. Up to now this has been quite successful and has improved the regional (Cerrado) and the Brazilian economies. However, rural depopulation, and concentration of income and land have arisen from the scale economy of the production system (Sarmiento and Pinillos 2005). The expansion of the soybean system has given rise to concerns that the increasing use of ground water, soil organic matter, and energy has increased the vulnerability of the system and resulted in the negative impact of ecosystem services. The increased use of irrigation water for year round production has increased the dependence on underground water resources (up to 400 mm during the dry season, that is 4000 m^{-3} per ha). Groundwater levels have been

lowered, stressing the importance of research and management on the regional water budget. In addition, soil organic matter (SOM) levels appear to be declining due to reduced crop residue inputs relative to the perennial grasslands of the native vegetation. In three different soil types under the wheat-soybean system, SOM decreased by 30 to 60% in six years (Landers 2001). Lastly, the energy inputs to the agro-ecosystem may largely exceed the outputs in terms of harvest, because of the fuel demands of mechanization, underground water pumping and industrial nitrogen fixation. The need to maintain the agricultural system through continued fossil fuel inputs may have long term negative social and environmental effects.

In this system, productivity appears to a significant degree to depend on the reserve of ecosystem capital stored under natural conditions. However, the intensification of agriculture may rapidly exhaust the availability of water, soil organic matter, and other ecosystem goods and services so that it will become increasingly difficult to maintain the cropping system, while also reducing chances for the recovery and maintenance of the natural systems. Monitoring of these critical ecosystem services will be needed to assess the rate of resource usage and the long-term effects of intensive soybean production.

Afforestation of grasslands within the high tablelands of southern Brazil.

The tablelands of southern Brazil are covered by a mosaic of subtropical grasslands (campos) and mixed montane forests. Since the 17th century, the dominant use of the grasslands has been extensive ranching (Nabinger 1998, Nabinger et al 2000, Palleres et al 2005, Overbeck et al 2007), with an average production of 60 kg live weight ha^{-1} y^{-1}, largely determined by the carrying capacity during winter. This production system was successful and ecologically sustainable until the late 20th century, when the opening of the regional meat markets resulted in declining economics of the cattle sector. As a result, areas under natural and secondary grasslands are being reduced at a striking pace and replaced by pine plantations. Notwithstanding the dramatic change implied in the transformation of what has long been a predominantly heterogeneous and open landscape into a forested one, an appropriate assessment of its possible ecological and societal consequences is still lacking. Concerns over the extensive land use changes affecting water dynamics, soil carbon levels, soil erosion, and biodiversity call attention to the risks implied by the whole-sale transformation of the original, diverse landscapes of the high tablelands of southern Brazil. Even though afforestation may be a profitable opportunity for ranchers, consequences on soil quality may well limit productive land use in the medium term unless a more ecologically friendly technology is implemented for planting and harvesting.

Implications of biofuels production

In recent years, demand for biofuels has affected cropping systems in the Americas. Oil companies, commodity dealers and plant breeders have developed complete production chain packages that include new and more efficient fuel crops, marketing, and oil extraction plants in many agricultural regions. There are currently two main biofuel

categories, one uses sugar or starch crops to produce ethanol for gasoline replacement, the other uses oil plants for diesel. Crops that are used to obtain ethanol are sugarcane, corn and sorghum, while biodiesel is produced from ricinus, jathropa, soybean, canola and sunflower. The increased demand for biofuels greatly impacts food supply. Globally, to attain a 10% share of the diesel would require the total production of vegetable oils.

This increased demand for biofuels will impact both environmental and social characteristics of agricultural lands. The expansion of cropping areas needed to meet increasing demands of fuel crops will affect marginal agricultural lands that are inherently more susceptible to degradation under more intensive land use. In addition, the competition between biofuels and food production has the potential to alter pricing of basic commodities and affect food prices. This switch may call for social adjustments to maintain affordable food supplies. Legislative actions may be needed, such as those proposed by Mexico recently to maintain food maize price at affordable levels.

Functional biodiversity shifts in human-impacted tropical forests

Much of the current discourse on the fate of tropical moist forests has emphasized habitat destruction. It is now important to integrate remnant or restored forest into economically, socially and ecologically sustainable landscapes, to conserve biodiversity and develop non-traditional economic activities such as ecotourism. Such landscapes will be mosaics of different land uses with different functions, providing ranges of goods and services to people linked with the landscape in different ways - from those who live on the land, to those living elsewhere but consume products and utilize services provided by the landscape. Some of the ecological services, such as carbon sequestration and storage, yield global benefits.

Part of the cover of sustainable landscapes, then, will be fragmented natural tropical moist forest. Some forest areas may be dedicated to the provision of environmental services such as regulation of the hydrological cycle, carbon fixation and storage, conservation of natural communities or species, the provision of ecological connectivity to strengthen the resilience of native biodiversity in the face of global change, and aesthetic value or recreational use. Other areas will be dedicated to sustainable production of timber and non-timber products; some marginal agricultural land will be assigned to the restoration of forest and the goods and services it provides (Aide 2000, Finegan and Delgado 2000). In addition, many agricultural production systems may be managed with an increasing awareness of the importance of biodiversity to sustainability, and therefore an increasing contribution to biodiversity conservation (Harvey et al. 2006).

Traditional conservation efforts have emphasized human threats to species, though more recently, planning and priority-setting for conservation have focused on ecosystems as conservation targets (Noss 1996, Jennings 2000). An awareness has also grown of the need to conserve ecological processes that generate and maintain biodiversity under environmental change, and that support services to society. What knowledge is needed to understand and manage human impacts on forest functions that underpin the provision of goods and services? The question may be addressed by evaluation of changes in forest functional composition and diversity, applying the

principles of plant functional ecology (Cornelissen et al. 2003, Díaz et al. 2004; Finegan et al., chapter 13, this volume). Ecosystem functions such as carbon storage and sequestration are "maintained" to some extent under most human forest uses. Impacts on seed dispersal, pollen movement and therefore gene flow are not well understood for many trees. Some examples of substitution of service providers lost in human-dominated landscapes are documented; examples of this are the replacement of extinct megafauna by horses and cattle in the dispersal of seeds of some Central American dry forest tree species (Janzen 1981), and of native bee pollinators by Africanized honey bees in pollination of the Amazonian rain forest tree Dinizia excelsa (Dick 2001).

To link the quantity, quality and sustainability of ecosystem services to biological diversity remains an important challenge. To do this we must first develop and validate practical ways of measuring functional composition and diversity in tropical moist forest. Existing principles of tropical forest ecology permit an initial set of predictions concerning human-caused change in the functional composition and functional biodiversity (FB) of the forests. The FB to be found amongst forest tree species was probably underestimated in the past and the task of reevaluating it has barely begun (Finegan et al., chapter 13, this volume). Knowledge of FB shifts and their implications for the provision of ecological services by the forests is therefore incipient.

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4.
Conservation to sustain ecological processes and services in landscapes of the Americas

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Ecosystem services are fundamental to the development of sustainable landscapes but are largely ignored or taken for granted in land management strategies. Ecosystems, and the ecological processes that define them, form the natural infrastructure supporting human activities to enhance the economic and social well-being of communities. This chapter draws upon results from across the IAI research network and associated programs to review our current knowledge of ecosystem processes that should be considered when making decisions on designing areas for protection in cultural or highly-intervened landscapes. Taking ecosystem services into consideration will help decision-makers identify the different components of a landscape that are providing essential services and which should be preserved within a sustainable landscape development plan.

Why should ecosystem services be conserved?

Ecosystem services are the products of natural ecosystem processes that have value to humans. The Millennium Ecosystem Assessment classifies ecosystem services as supporting, provisioning, regulating, and cultural (MEA, 2005). The most fundamental processes supporting life on the planet are classified as *supporting services* and include soil formation, nutrient cycling, and primary production. Ecosystem services that provide the basic goods on which humans and other organisms depend are classified as *provisioning service*s and include food, water, fiber, and fuel. *Regulating services* are those that influence the supply of goods by purifying water, controlling disease, regulating climate, and regulating pollination of plants. Finally, *cultural services* reflect the importance of ecosystems in fulfilling the aesthetic, spiritual, educational, and recreational needs of humans.

We start with the hypothesis that undisturbed, functionally diverse ecosystems offer a full spectrum of supporting, regulating, and provisioning services, each operating at its nominal capacity given local controlling factors (climate, geology, successional status, etc.) and each interacting with adjoining ecosystems to support landscape-scale ecological processes. Forest and woodland ecosystems provide goods such as food, fiber, fresh water, and medicines, as well as important regulating services to purify air, conserve soils, control floods, and control disease outbreaks (Nunez et al. 2006). In this age of global climate change, forests and woodlands are also important areas for carbon sequestration. Dry land ecosystems provide many of these same services to lesser

magnitudes as a function of local climate and relative abundance of vegetation (Shakleton et al. 2007). River, lake, and wetland ecosystems are a landscape's most valuable sources of water, but they also provide regulating services that control flooding and pollution, retain sediments, and reduce disease. Examples of critical landscape-scale connections include the riverine transport of water derived from headwater forests to support drier downstream ecosystems and the annual migrations of birds, fish, and other organisms between ecosystem types to complete individual biological cycles.

Virtually all landscapes have been subjected to some degree of human intervention, the most widespread of which are agriculture, ranching, and silviculture for food, fiber, and bioenergy production. Intensive development of these activities is usually accompanied by damming and diversion of rivers and draining of wetlands. In the course of these interventions, regulating and supporting services of the converted land are commonly degraded and landscape scale ecological linkages and processes are disrupted. While there are important examples of landscapes that have supported mixed human use for centuries (Grove and Rackman 2001, Plieninger et al. 2006), degradation of supporting ecosystem services more commonly leads to declines in the yields of crops, livestock, and plantations. Such declines are clear indicators of a loss of ecosystem services, although they may not be recognized as such by land managers. When this occurs, land managers and the larger society are forced to invest additional resources to substitute or restore supporting services. Some services, such as water supply and regional biodiversity that depend on landscape-scale ecosystem configuration and connectivity, may be severely degraded and recoverable, if at all, only at enormous social and economic cost (e.g. the $8 billion Everglades Restoration Program in Florida USA).

In order to sustain productive uses of landscapes at minimal costs, strategic action should be taken to conserve ecosystem services. This can be accomplished by conserving the ecosystems that provide the services (e.g. wetlands for flood protection) or by emulating natural ecological processes on managed lands (e.g. maintaining vegetation buffers around orchards to provide habitat for pollinators). In either case, effective maintenance of ecosystem services requires knowledge about the ecological processes providing the services, and of the mechanisms that link these processes across landscapes. The specific type of ecological knowledge useful to decision-makers will vary according to the intensity and configuration of land use in a given landscape. For example, in landscapes in developing regions characterized by low-intensity use, knowledge of ecosystem services linked directly to the provision of food, fiber, and water may be most important. Conversely, in high-intensity use landscapes dominated by agriculture and urban areas, knowledge of ecosystem services linked to pollution reduction may be most important.

Cost-reduction is a powerful motivation for the conservation of ecosystem services, and the valuation of these services is a major area of economic research (Turner et al., 2003). Decision-making processes at all levels would certainly benefit from a science based cost-benefit valuation framework to assess ecosystem services and conservation interventions (Naidoo and Ricketts, 2006). For example, the externalities represented by soil erosion control, hydrological regulation, and sustained nutrient cycling, if incorporated into the cost-benefit analysis of a project that will deforest a spring-rich region, would clearly influence conservation decisions. The same principle could be applied to a managed system, where the costs of conversion to a more

sustainable agricultural production system could be compensated by the economic gains represented by the restoration of carbon to the soil, or by the increased infiltration of water to the underground reservoirs.

What ecological knowledge is necessary to advise decision makers on the most important ecosystem services to be conserved or restored when defining conservation areas?

While agreement within the scientific community has converged on the need to sustain ecosystem services such as hydrological regulation and soil erosion control, land use decisions are not generally influenced by existing ecological knowledge. This is true even when land use decisions involve setting aside areas of the landscape for conservation. Commonly this may be done to preserve one defined service of the ecosystem such as water production or the protection of a given species but little or no consideration is given to other services. Aside from the declaration of large, relatively pristine areas for conservation, where most ecosystem services are included in the conservation effort by default, the identification of areas for conservation in a landscape highly modified by humans should include a careful analysis of the services that need to be preserved. There is a wealth of data and information describing and demonstrating the consequences of impairment of vital ecosystem services caused by major land use changes across the globe. These include significant impacts on soil water infiltration rates, affecting flood regulation and soil erosion control; soil organic matter turnover rates, affecting carbon sequestration and nutrient cycling; and vegetation cover, affecting primary productivity, evapo-transpiration, and climate regulation.

Despite this, regions such as the Cerrado in Brazil continue to undergo widespread de-vegetation giving rise to erosion prone cultivated lands. The Pampas natural grasslands in Argentina are giving way to commercial forests that draw down the water table (Coutinho et al., chapter 8, this volume), fragile montane forest of the eastern slope of the Andes is converted to mountain-side cultivation that accelerates landslides and nutrient losses on steep slopes (McClain et al., chapter 11, this volume), and the Yucatan forests in Mexico are being converted to commercial plantations that cause contamination of the local honey production (Jimenez et al., chapter 6, this volume). Will ecological knowledge affect land use decisions so as to conserve or restore ecosystem services? If so, what knowledge is required?

Land managers are most likely to change their decisions when visible and meaningful indicators expressing the status of critical parameters of the populations´ livelihoods point to the need of interventions or adjustments of human conduct. The most important ecosystem services for humanity are the provision of food and of water. Without them sustained development is impossible. Ecological knowledge related to these services, expressed in the form of measurable and meaningful indicators, is therefore valuable for decision makers. We will comment on these two major ecosystem services (water provisioning and food security), and then elaborate a few case studies of environmental and social problems caused by land use change, highlighting possible solutions derived from ecological knowledge.

Water quantity and quality is a sensitive issue for decision makers both at the local scale (farmers, municipal authorities) and the national and global scales (policy makers and multilateral funding agents). Most ecosystem functions have implications for water resources, and their impairment threatens the provision of water of good quality at sufficient quantities to societies. Soil water holding capacity, especially in the tropics, depends on adequate levels of soil organic matter content to maintain soil structure (density, porosity, and aggregation). Reduction of soil holding capacity increases water losses via storm runoff and reduces groundwater recharge and dry season stream flows. Erosion control reduces the transfer of sediments and soil nutrients to the water system, thus conserving soil and water quality. Maintenance of this important ecosystem service can be achieved by conservation of the soil organic matter content and soil vegetation cover. As a last line of defense against sediment and contaminant fluxes to streams and rivers, riparian vegetation buffer strips can be maintained. These are important issues both in areas of rapid land use change, affecting rural populations that depend on the water for agricultural production, as well as in urban centers in need of hydroelectric energy and drinking water. Many cities suffer from high sediment loads and pollutants transported by rivers as a result of being located downstream of land that underwent land use change . The costs of making water from such sources potable are extremely high. This segment of the decision making process will certainly be influenced by ecological knowledge on the potential gains of conservation measures to improve water resources.

Some ecosystem services also affect food security, especially in marginal lands. Soil degradation in the tropics due to erosion and organic matter depletion significantly reduces the productive capacity of the land. The rural population in these critical areas faces serious problems of food security, as shown by Salcedo and Menezes (chapter 10, this volume) in the semi-arid Northeast of Brazil. Those authors demonstrate that restoration of ecosystem services through sustainable landscape management of the land is able to alleviate food security problems resulting from past land use changes. Ecological knowledge should then inform the different levels of the decision making process (farmers, government, etc.) about the risks and opportunities of manipulating and/or conserving ecosystem services of natural and managed environments, considering the resulting status of critical resources for the livelihoods of rural and urban populations.

If there is an urgent need to conserve these vital ecosystem services, how can ecological research influence this process? It requires a process of communication, in transforming ecological information into a format easily accessible and meaningful to decision makers at the different levels. Decisions are often based on immediate threats and risks posed to economic sustainability. Therefore ecological knowledge must relate to such potential threats. This is examined further in a separate chapter in this book (Stewart et al., chapter 2, this volume). The following case studies from the Americas illustrate some of the challenges of communicating the right information to the appropriate stakeholders.

Water availability in dry ecosystems

In tropical dry landscapes there is a highly contentious conflict between increasing human demands on water resources and the varying water needs of the different

components of the landscape such as forest, mangroves, wetlands. The biological wealth is currently endangered by growing human water demands. Increasing and uncontrolled use of limited water resources for irrigation, human consumption, and tourism - a phenomenon that translates into new dams, deviation of rivers, and the use of river discharge during low-flow seasons - jeopardizes the future of tropical dry forest ecosystem. In this scenario, decision makers are faced with the imperative need to limit river flows and groundwater withdrawal to save the aquatic and terrestrial ecosystems as well as to cope with society demands. In this scenario scientific information about river, estuarine, wetland and marine ecology is a must. Additionally, information about the hydrological interactions of different types of land covers is required for the development of a sound water management plan. Last and more importantly, climate change, understood as a rise in air temperature and a modification of rainfall regime, modifies the hydrological cycle, altering the ecosystems functions and services which in turn will increase the vulnerability of the society and make sustainability more difficult to achieve. Maintaining and enhancing ecosystem functions will increase the landscape resilience to global change.

Pollination and pesticides

Pollination is one of nature's services often taken for granted. Pollinators are essential for crops, as well as for maintaining plant populations. Native and locally managed European honeybee colonies provide this service. In addition, apiculture can be an important source of income for rural communities. Unfortunately, insecticides used to kill agricultural pests in rural areas can also kill beneficial pollinators.

In the Yucatan Peninsula beekeeping has been an important economic activity as nearly 40% of Mexican honey production comes from this region. At present, this activity has been affected by land use change, as well as pesticide utilization. A consequence of pesticide utilization is the decrease of hives and the quality and marketability of honey, as the honey gets polluted with agrichemicals making it unsuited for organic international markets that require certification of the product. In order to maintain and improve this activity, it is necessary to decrease the use of pesticides through the establishment of other pest control methods. Since pollinators depend on native plants and habitats to live and feed, conservation of native vegetation can contribute to improve apiculture, as well as produce habitat for predators and parasites that control pest populations.
        Intensive agricultural cropping practices often rely on mono cultural practices. Monocultures are prone to pathogen and pest damage. Allowing biologically diverse strips (hedge rows, native plant community remnants) to exist adjacent to these fields provides habitat for organisms which prey on the undesired organisms.

Drought resistance

Hamel et al. (chapter 17, this volume) highlight the potential benefits to ecosystem function of increasing the number of plant species. Climate models indicate a climatic

change for the Canadian Prairies towards greater aridity. The present agricultural annual crops and monoculture forage could potentially have insufficient capacity to produce economical viable biomass. Stands of multiple drought-adapted species may provide greater biomass than the typical single species pasture. They note a trend towards greater drought resistance with increased diversity, possibly linked to greater exploration of the soil resources and to greater soil microbial diversity, which endow the system with greater water and nutrient use efficiency. Restoration of plant diversity in this instance restores ecological services.

Soil erosion and flooding regimes

The Taquari river watershed belongs to the Paraguay river sub-basin, part of the La Plata river basin. It has an area of 80,000 km^2, 50,000 km^2 of which is in the Pantanal lowlands, and the remaining 30,000 km^2 comprising the headwaters, located in the Brazilian Cerrados. Its sandy soils, irregular topography, and annual precipitation of 1500 to 2000 mm, concentrated in one rainy season from November to March, make it highly susceptible to soil erosion. The last 30 years witnessed the loss of most of the native vegetation of the Upper Taquari river basin, and its substitution by soybean and cultivated pastures, with the predominance of the latter (Silva et al., 2005a). The result was widespread severe soil erosion, with the formation of enormous gullies along the drainage lines of valleys, and the destruction of a significant portion of the riparian vegetation (forests and *veredas*). Apart from the obvious effects of the depreciation of eroded land and loss of agricultural yields resulting from the depletion of organic matter and impairment water regulation, effects in the down-stream Pantanal region are highly significant. The Taquari River suffers severe siltation, and the seasonal flooding regime of the Pantanal lands was seriously affected. Many farmers abandoned their properties and numbers of *colonos* lost their livelihoods, which largely depended on cattle ranching on the previously productive natural pastures (Silva et al., 2005b; Curado, 2005). Currently, decision makers are seeking solutions. Ecological knowledge could provide a better understanding of how carbon allocation and organic matter decomposition is regulated in the Cerrado's natural and managed degraded systems. This knowledge could aid in the development of improved managed systems, with increased carbon inputs and retention in the soils to enhance soil organic matter content and enabling the recovery of the soil water holding capacity. This should regulate the flow of water and reduce soil loss through erosion. Additionally, knowledge on hydrogeology and biodiversity can guide decisions regarding the areas to set aside for preservation.

Multiple Benefits from Riparian Conservation to Preserve Soil Fertility

In inter-montane valleys of the Andean Amazon, fertile soils on level surfaces are largely confined to alluvial deposits in riparian zones bordering streams and rivers (McClain et al. chapter 11, this volume, McClain and Cossio 2003). Indigenous and colonist communities in the region perceive the value of these areas and actively conserve them to protect processes maintaining soil fertility. As a consequence, agricultural activities in

riparian zones are largely confined to cultivation of high protein crops that will not grow effectively on upland soils without the application of fertilizers.

Inhabitants of the region do not, by and large, perceive the many ecosystem services of riparian forests in protecting the quality of surface waters from land-based sources of pollution (sediments and solutes) and providing critical habitat and food to aquatic biota. While people do not perceive them, these services are critical to the health and well-being of local people because they take the majority of their drinking water from these surface water sources and obtain a large part of their nutritional requirements from the rivers (McClain et al. 2001).

How do local values, knowledge, and institutions affect decisions about conservation of ecosystem services?

Knowledge about the conservation of ecosystem services does not come exclusively from ecological scientific research; it may be derived from peoples with long traditions of successful use and management of the landscapes in which they live. Sustainable development requires decision-making attitudes towards production, consumption, and lifestyles that are compatible with the needs of environmental protection (Antrop 2006). It has been well documented that local communities generate knowledge about their surrounding environment over time that allows them to address problems of resource optimization.

Some indigenous groups like the Mayans in Mesoamerica have done this for centuries in a mosaic of landscapes and in changing environments, implying knowledge and management of local variables like soil and plant species despite the complexity of the system (Rainey, 2005). More recent colonizers of the American continent like the ranching communities of North America, the Brazilian Pantanal, and the Argentinean Pampas also show a profound understanding of the grassland ecosystem that supports them, they "know the land." This knowledge is mainly derived from long term anecdotal experience, often over generations. In Saskatchewan, Canada, this can be seen in the correlation between the location of extensive cattle production systems and remnant native prairie. Decisions to retain the native prairie landscape are often based on topography, soil textures, local climate, forage potential and lifestyle.

Similar examples could be found in other regions of the Americas, but it is important to keep in mind that traditional knowledge is not complete and not always based in fact. It is therefore important that traditional knowledge is confirmed and complemented by science. In most cases, the most effective way forward will be to hybridize knowledge derived from the ecological sciences and local people, as this may catalyze communities to actively participate in and benefit from sustainable management of the landscape.

The motivation for engaging local peoples stems not only from a desire for knowledge they might provide but also from an obligation to provide support to their efforts. The farmers and communities in the Americas, especially those in fragile and more vulnerable underserved areas, require support to strengthen their capacities to improve the management of their landscapes. In cases where their voices are unheard and politically marginalized, they have little influence on ecosystem management policy

formulation and implementation. In many instances they are located in areas where access to agricultural and ecosystem management research support services are inadequate or lacking. Therefore, they do not benefit from scientific and technological advances in a timely manner, particularly under the challenges of climate change. There is, therefore, a need for research institutions to support integrated research and extension on the management of ecosystem services, to assist these under-represented and sometimes under-served communities. The IAI's network of scientists with similar missions, should contribute to the process of informing policy, communities and other stakeholders that have a direct and recognized need for the ecosystem services.

Local knowledge systems can to contribute to sustainability in diverse fields such as biodiversity conservation and maintenance of ecosystems services, soil quality monitoring (Barrios et al., 2006), sustainable water management and management of other natural resources. Conservationists at the national and international level can benefit from working with local communities to identify crucial areas in landscapes that should be managed to preserve important services. The number of pristine ecosystems that can be protected under the traditional concept of a National Park is quickly diminishing, and the new conservation efforts should be focused on managed areas and the ecosystem services they provide.

Considering local knowledge contributes both to the equity, security and empowerment of local communities, which makes them stronger stewards of the sustainability of their natural resources. Local knowledge helps in scenario analysis, data collection, management planning, designing of the adaptive strategies, in learning and feedback and institutional support to implement policies.

Local knowledge and scientific knowledge can be complementary but this requires a dialogue between holders of knowledge and acknowledgement of differences in value systems. A system for managing biodiversity can then be formulated in a way that not only respects these two sets of values, but also builds on their respective strengths. Local perceptions and values can be used and improved to restore and manage natural resources. Therefore, participatory approaches are needed to convey scientific knowledge to reinforce local existing knowledge.

Urban consumers, removed and detached from the land, have a strong influence on production choices of rural producers. There is a trend among wealthier sectors of society towards more environmentally friendly produce. In turn, producers in the field can potentially influence consumer choices by communicating the ecologically sound practices used in the production of their goods. The chapter by Castellanos and co-authors in this volume (chapter 5) examines further this two-way communication between household-level decisions at the farmer level and worldwide commodity chains.

How sustainable landscapes can contribute to solutions to global environmental changes

Many of the global environmental changes we are currently experiencing are the sum of smaller-scale changes that humans have caused in various ecosystems. Such changes have been induced to increase benefits from a particular ecosystem service (food, energy, fiber, etc. production) at the expense of reducing the benefits from other services. We

now understand that we cannot modify substantially one particular ecosystem through our technological advancements without modifying other ecosystems that are interconnected, which in turn will impact regional or global conditions. The level of global impact will of course depend on the size and type of local disturbances; but even small disturbances, if repeated in many places, can produce global changes.

The interconnectivity among ecosystems at the regional and global level can be complex, making it difficult for scientists to fully understand processes linkages, and increasing the uncertainty of future scenarios. The effect of global warming on species distributions illustrates this interconnectivity. One can argue that a change in species ranges will leave gaps within communities which permit the invasion of alien species. Within the sagebrush communities of the US Great Plains, the invasion of *Bromus tectorum* has resulted in a change in the local microclimate. Also, *B. tectorum* has a rapid growth cycle with a flush of growth during the cool, moist spring and an early onset of senescence resulting in large amounts of dry litter accumulating during summer months. This dry litter results in increased frequency an intensity of fires. The result is a degraded ecosystem with a severe reduction in productivity, decreased carbon sequestration (loss of the sagebrush component) and an environment that no longer supports the original ecosystem. This particular case illustrates the connectivity between climate change, biodiversity and nutrient and water cycling. To reverse this process would require concerted effort and energy.

Trajectories resulting from global environment change are not necessarily all negative. The very fact that we have been able to impact negatively the way that our world functions by making seemingly local modifications to our ecosystems suggests that we can redesign the modifications of our environment to include basic principles of ecosystem functioning and our managed ecosystems more sustainable. If critical ecological services are identified early enough (potentially through monitoring and identification of trends and indicators), steps can be taken to maintain and reinforce them for a positive outcome.

Sustainability should not only be viewed in a temporal scale (making sure that ecosystem services be available for future generations) but also in a spatial scale which varies in size depending on the particular ecosystem service considered. In the long term, it does not matter if one can keep a particular system producing a particular service for many years if the very existence of that system is threatened by problems of regional or global proportions. For example, one could determine the sustainability of an agricultural field by monitoring its productivity during time. But productivity can be maintained through nutrient cycling, pest control and water availability which a farmer can artificially maintain for his field for some time. Yet he will do so at the expense of high energy and material inputs that will result in a high potential of polluting neighboring ecosystems, which in turn will reduce overall sustainability.

Increasing the resilience of ecosystems, particularly of the services they provide, will lead to less vulnerable landscapes and provide a buffer against global environmental changes. Biodiversity of the appropriate level (still to be determined for many ecosystems) provides redundancies which decrease the risk of complete ecosystem failure. An approach being explored to potentially ensure that the right species and components are present in a system looks at their functionality (Finegan et al., chapter 13, this volume). Other examples of actions that conserve ecosystem services to help us

buffer against global changes include: defining the environmental flow regime at which the aquatic, estuarine and marine ecosystems will be less vulnerable to a drought; promoting drought-resistant crops and pastures for farmers to be better prepared to face water scarcity; promoting urban populations, industry, and agro industry to be more water and energy efficient; and promoting the restoration or creation of wetland ecosystems in coastal or low-lying regions prone to flooding.

Concluding remarks

Demands from growing populations and greater needs for basic services of clean water, food, and energy, are placing a stronger pressure on most ecosystems of our planet. The era of protecting pristine ecosystems in reserves with very little human intervention is now giving way to a time when land managers face the more complicated question of optimizing the different components of human-modified landscapes to optimize the production and sustainability of services and goods. In doing this, it is important to consider not only the usual and more obvious services of food and water production, but also other, less evident, but equally important services. Services such as soil nutrient regulation and cycling, surface and ground water flow control, and climate regulation are not always evident to people making decisions on land use changes, in part because they act at longer time scales and on larger geographical areas.

If we want to achieve sustainability in land management practices, we must take into consideration different temporal and spatial scales in our analysis of the various services provided by our surroundings that are fundamental for our subsistence. Such ecological thinking should permeate discussions outside academia to help decision-makers at all levels, from the farmer deciding on a cropping system to the national-level bureaucrat discussingenvironmental protection. Even highly-modified ecosystems are providing different levels of supporting, provisioning and regulating services that are crucial to the sustainability of a given region and eventually of the world. When we visualize individual, local decisions as adding up to larger, global impacts, we will be on the right path to mitigate global environmental changes and to adapt to these changes through the development of more resilient land use systems that include the right combination of production and conservation.

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5.

Understanding the resources of small coffee growers within the global coffee chain through a livelihood analysis approach

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Livelihood analysis is an important tool for understanding human-environment relations at household level (Ellis 1998; Bebbington 1999) and for examining the implications of rural households' decisions for their livelihood security and the environment on which they depend. The approach has helped explain how households organize their assets and resources towards viable and sustainable strategies (e.g., Francis 2000) or why some households are unable to cope effectively with exogenous stressors and changes in their institutional or biophysical environment (Mortimore and Adams 1999; Morris et al. 2002; Eakin 2006).

Livelihood analysis has been used to illustrate how household members interact with institutional constraints and opportunities at local, regional, and national scales, and what attributes within the household facilitate or inhibit effective engagement with institutions at these different scales. One challenge for livelihood analysis in rural communities is to understand how households engage with changing market circumstances under economic globalization. Globalization is not simply an exogenous stress on households: rural communities can interact with the global economy to shape their opportunities within a structure of rapid change (Bebbington 2001). Whether households do become actors or not in struggle with globalization is of critical importance for rural development.

We here explore household participation in global commodity chains. The production and marketing of cash crops such as coffee in a globalized economy presents an interesting opportunity to develop an integrative analysis of how small farmers, drawing on household assets, make local agronomic decisions in the context of changing global markets.

A novel approach: extended livelihoods

The livelihood approach allows the researcher to analyze a unit of production in which the rural family is the main actor. Households have access to a set of livelihood assets that provide their means for living. Households live in a context of vulnerability to critical trends, socio-economic shocks and seasonality that can undermine their command over their household assets (DFID, 1999). We here use a livelihood framework to analyze farmers' responses to markets, climate and pests in the context of household characteristics, institutional, cultural, and organizational factors (Figure 5.1). The farm household is the primary "exposure unit". The impact of stressors on a household will be in part a function of the household's assets. These assets are measured in terms of five sets of "capitals": social, financial, natural, physical and human (DFID 1999). The

response of a given household to stressors will be influenced by the relationship of the household to the institutions that govern the allocation and use of resources related to markets, information availability and social organization. Together, the institutional context and the households' asset base will affect the response strategy pursued by the household.
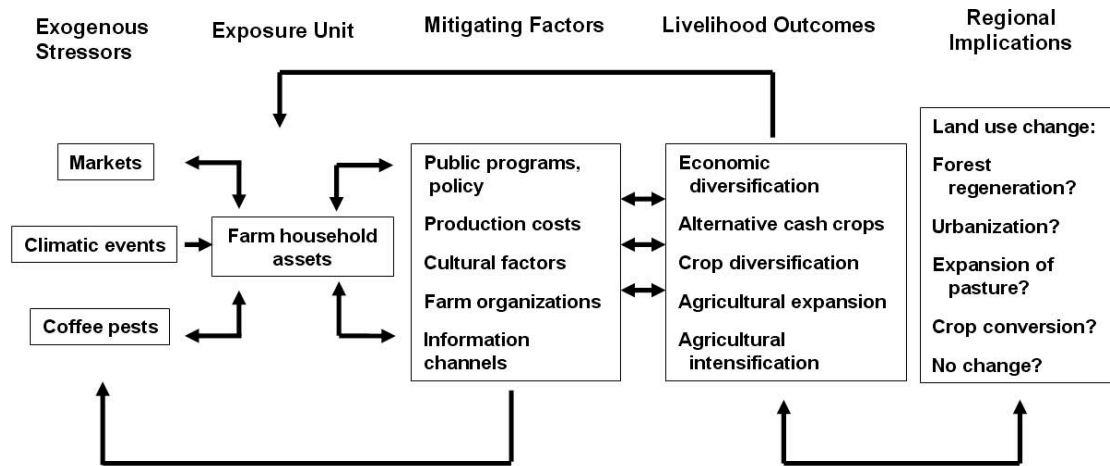
Figure 5.1: Framework for analyzing farmers' responses to stress

In the global change literature, the livelihood approach has been used to gain insight into how households adapt to changing resource availability resulting from environmental stress (e.g., Eakin 2006, Adger 1999). At the same time, the concept has been linked with other agro-ecologic, economic and social approaches. Mendez and Gliessman (2002) for instance proposed the integration of an agroecology approach with approaches from the social sciences as a basis for interdisciplinary research in natural resource management and rural development in the Latin American tropics.
Since households are not isolated from their surroundings but are vulnerable market trends and shocks, their sustainability does not depend only on the way they manage their resources. Stoian and Donovan (2004) therefore propose the integration of livelihood with value chains in analyzing households' decision-making process to arrive at various livelihood strategies.

In extending the livelihoods approach to global commodity chains, we start by considering commodity pricing as one of the main sources of household vulnerability. We build our discussion around the specific case of strategies used by coffee growers in Mesoamerica to confront the recent crisis resulting from very low international prices (Eakin et al., 2006).

When small farmers supply their products to markets, they participate in commodity chains. We must take into account that chains are characterized by links from farm production to consumption processes and are internationally connected in different ways. The most usual connection shows when considering exporting goods as in the case of coffee. Global commodity chains are then understood as networks of production. Four dimensions can be distinguished in these networks: first the production system, which

includes production stages, agents and different levels of horizontal and vertical integration. Second, the location pattern refers to production activities organized in different locations. It depends on local conditions and the production organization, which are usually determined by the most influential agents of the chain. The third dimension includes policies and institutions. Governments and organizations, both local and international, shape the institutional framework in which agents operate along the chains. Fourth, and very decisive in the overall organization of the chains, we consider the governance system. Power along the chain is unbalanced, and options for small farmers depend on the kind of governance that the chain has. Small growers usually are participating in demand-driven chains, which means that traders, food industries and supermarket chains have the most profitable and influential position. For commodities such as coffee, this imbalance along the commodity chain also reflects geopolitical imbalances: the primary producers are concentrated in developing nations in the tropics, where they typically far outnumber more powerful actors in the other stages of the commodity chain who tend to concentrate their activities in more industrialized nations (Díaz 2003).

Competitiveness of small farmers in a commodity chain is related to their position along the chain. Farmers are positioned at the first stage of the chain, usually the most risky and less profitable one. Positioning is a strategy to increase competitiveness based on product differentiation or lowering costs. Improving the position of farmers can be achieved by vertical integration through agroindustry organizations in which farmers can venture into the commercialization process. Stronger market power can be developed by horizontal integration, that is, association of producers within the same segment of the chain. A strong social capital built on networks of trust between farmers is key to this type of horizontal linkage.

In commodity chains, improved competitiveness has been associated with upgrading processes through upgrading functions and positions within the chains. Four ways have been recognized to upgrade primary production in global commodity chains (Gibbon 2001; Humprey and Schmitz 2000):
- Process upgrading through re-organization of the production system or introduction of state-of-the-art technology, by which producers may capture higher margins for unprocessed commodities.
- Product upgrading by moving into more sophisticated product lines and producing new forms of existing commodities.
- Functional upgrading through acquiring new functions in the chain.
- Inter-sector upgrading through applying competences acquired in one link of a chain to a different sector or activity.

Upgrading to manage economic shocks

The coffee chain, as many other agricultural food chains, is demand-driven. This makes the changes and trends on the demand side very important for coffee producers. Segmentation, concentration and product differentiation characterize markets of the chain. Those factors determined by the governance system which is in the hands of traders and roasters.

Quality is becoming an important factor governing the chain, while governance is related with the definition of the terms of chain membership. Coordination between leading firms and their suppliers is largely "hands off", because firms have been able to embed complex quality information into widely accepted standards and certification procedures (Ponte and Gibbon, 2005). Quality standards developed by leading firms influence producer prices and in part determine household vulnerability since fulfilling them has become a condition for being incorporated or excluded from a given chain.

Upgrading processes is a household strategy to fulfill quality requirements demanded by the chain. In Table 5.1 we propose some relationships between upgrading options and livelihood changes for coffee growers. Upgrading processes at the household level alleviates economic vulnerability through inclusion in more profitable chains and thus strengthening resilience to economic shocks.

Table 5.1: Upgrading options and required livelihood changes for coffee growers.

Type of upgrading	*Example*	*Livelihood Changes*
Process	Yields increasing, maturity and disease control. Environmental and social considerations: organic, bird-friendly, and fair-trade coffee.	Technology change, training, standards
Product	Different coffee quality to consumer (gourmet coffee, for example).	Market knowledge
Functional	Vertical integration (first processing, roasting)	Cultural change, strategic behavior
Inter sector	Product or activity diversification: fruits, ecotourism, services to other producers	Flexibility

Farmers' vulnerability and product upgrading in Veracruz, Mexico

While product and process upgrading has the potential to help coffee farmers to reduce their livelihood insecurity, smallholders face numerous challenges in their attempts to change their role in the coffee commodity chain. These challenges have become particularly evident in recent years as coffee farmers have struggled to adapt to historically low coffee prices, rising world coffee stocks and new processing technologies that have made lower-quality high-altitude coffee particularly uncompetitive (Ponte, 2002). Because coffee farming around the world is largely undertaken by smallholder growers using family labor and assets as a basis for production, an analysis of smallholder coffee farmers' production strategies must examine both the structure of their livelihoods and the nature of the commodity chain in which they participate.

In 2003, two communities were surveyed in the state of Veracruz, Mexico as part of a project exploring the implications of the changing coffee market for smallholder farmers in Mexico, Guatemala, and Honduras (Eakin et al., 2006). Central Veracruz is a region with a long history of coffee production in Mexico and was an important commercial center for coffee in the 1980s, when the Mexican Coffee Institute (INMECAFE) was heavily involved in the provision of inputs, credit and technical support for smallholders. In the mid-1980s, INMECAFE was also marketing a substantial portion of Mexico's coffee harvest (Martínez Morales, 1997). Smallholder farmers, most with less than 2 ha of coffee, were organized by INMECAFE into small credit unions, through which they acquired seedlings, fertilizer and other inputs, and sold their coffee cherries for processing in INMECAFE's facilities. This arrangement distanced smallholders from processing.

The international market at this time was governed by the International Coffee Agreement (ICA), which established export quotas for each member country. The guaranteed placement of Mexican coffee in the international market provided little incentive for investment in coffee quality. The emphasis of sector policy was on volume and yield improvements (Martínez Morales, 1997). Technical support was provided for planting improved coffee varieties and introduced shade tree species, but not for building local capacity for processing, quality control, product enhancement or improved marketing.

Circumstances changed dramatically in 1989, when the ICA collapsed. INMECAFE was disbanded, and with it, the credit unions and farmer associations which had supplied coffee to INMECAFE. In Veracruz, many of the coffee processing plants (beneficios) were transferred to smallholder communities to manage. By the end of the 1990s, most of these facilities had fallen into disrepair, gone bankrupt or were otherwise being mismanaged. Meanwhile, in the face of declining global prices for coffee, many international agencies were arguing for process upgrading, considering end product and final consumption trends as a means of improving livelihood security for Latin America's smallholders (IDB/ World Bank/ USAID 2001).

A livelihood approach was used to understand the implications of these changes in Veracruz. In 2003 data was collected for 60 households on household assets; demographic characteristics; access to technical support and financial services; household losses to price decline, climatic problems and pests; and the strategies and decisions with which households responded to the livelihood stressors they confronted. Interviews were also conducted with large-scale producers with more than 20 ha and technical experts.

The research revealed that process-upgrading may be the best option to address smallholder vulnerability to market shocks. However, this requires farmers to overcome a number of obstacles related to the historic relationship of farmers to the public sector, the degree of trust farmer's place in their neighbors and fellow farmers, as well as the availability of key assets such as information and credit.

Over 80% of the households surveyed reported a decline in household income since the late-1990s, when coffee prices began to decline precipitously in Mexico. Farmers reported difficulties in acquiring basic necessities, and having to reduce fertilizer and labor inputs. While the economic difficulties provided a trigger for changing production strategies in order to enhance livelihood security, households confronted significant obstacles in doing so.

According to experts in the Veracruz coffee sector, one of the most attractive options for smallholder coffee farmers was process upgrading. Mexico is one of the world's largest producers of organic coffee, and while the prices for conventional coffee were hitting rock-bottom in the period 2000-2003, farmers of organic coffee were receiving a premium for their production. Nevertheless, unlike farmers in other states of Mexico (e.g. Chiapas and Oaxaca), none of the farmers in the two communities surveyed or in much of Veracruz were participating in the certified organic market.

Farmers who wish to comply with the strict production standards and practices for organic coffee certification must be well-informed on how to participate. They need to have access to technical assistance, financial support and social networks to make the adjustments to their production practices. Elsewhere in Mexico, farmers' participation in organic and fair-trade commodity chains has been facilitated by membership in farm associations, often affiliated with ethnic or religious groups that provide such support. In the two Veracruz communities, only 15% of households reported receiving technical assistance and just over one-third of households had received credit in the five years prior to the survey. Only 30% of households reported belonging to either a formal or informal farm-level organization. The majority of farmers reported significant suspicion and distrust of such organizations, and reluctance to engage in new production practices that would require such social collaboration. It was also clear that the prolonged crisis in the Mexican coffee sector had had a profound impact on how the activity was perceived locally. The average age of the farmers surveyed was 51, and few farmers indicated that their children were interested in pursuing coffee as a primary livelihood activity in the future.

Thus in this particular case study, key livelihood resources, human, social and financial capital, were the enabling assets for households to adapt to and participate in new market networks and commodity chains. An aging population, distrustful of collaboration and organization, and lacking financial support, is unlikely to have the capacity to engage in product and process-upgrading. In contrast, large farms in the region were actively engaging in process, product and functional upgrading. While relatively few in number, these family-owned commercial farms had never been engaged in the relatively patronizing relationship with INMECAFE that had characterized smallholder farming in the 1980s in Veracruz. Several of these farmers were involved in other stages of the coffee commodity chain as managers of private processing plants. These producers were eligible for small-business loans from federally-backed agricultural lending institutions. As prices began to fall, these farmers leveraged their processing skills and financial assets to improve product quality and engage in other stages of the commodity chain. In 2003, it was common to see such farms selling roasted and ground coffee, and some farms were experimenting with selling coffee "in the cup" in rustic coffee shops. The success of these strategies has yet to be seen, as further product (cup value) upgrading may be needed. Many of the farmers had relatively little experience in coffee roasting and retail, and domestic demand for coffee in Mexico is relatively stagnant. Nevertheless, the contrast between the two classes of farmers in Veracruz illustrates the importance of household livelihood assets and capital in farm-level adaptation to market change and economic opportunity.

Conclusions

Analysis of livelihood, the capabilities, assets, and activities required for economic life, has been applied to help the understanding of rural household decisions in a context of external vulnerability provoked by market trends, shocks, and seasonality. The most important factor of vulnerability for coffee growers is economic, especially for smallholder farm households. Economic factors of vulnerability are related to the competitiveness of growers based on their position and positioning in commodity chains. Rural households have very low degrees of freedom to control the economic shocks which derive from unstable or declining prices. Coffee growers are part of a global chain that is governed by traders and roasters who determine prices and market requirements.

However, the participation of rural households in an international chain allows them to know the market requirements and to take advantage of the opportunities for upgrading in order to reduce economic vulnerability and improve resilience to economic shocks. At the farm level, quality improvement processes can be developed to differentiate products in the downstream segments of the chain. For coffee, farmers can learn to distinguish their products for niche markets (gourmet, organic, fair trade) through both product and process upgrading. Strategies and policies can be designed to help farmers deal with market volatility and improve their command over the resources they need to participate successfully in markets. The combination of such internal and external actions should make livelihoods more sustainable.

Nevertheless, the case of Veracruz illustrates that there are important challenges that need to be overcome if farmers are to participate in the coffee commodity chain to reduce livelihood insecurity. Organization is a critical first step for farmers, and organization is a function of household command over social capital. Social capital is difficult to build; to be most effective it must emerge organically within farm communities. Policy can facilitate this process by reducing obstacles to farm-level organization and by discouraging the external political manipulation of farm associations. The institutional and socioeconomic factors that mediate how households are able to use their assets require attention. Providing access to market and environmental information and technical support can be critical in order to develop upgrading processes to participate in higher value chains. The innovation in strategy of medium to large-scale coffee producers illustrates that more effective participation in the coffee commodity chain may be possible. The challenge is to work with the existing constraints that define smallholder livelihoods in order to enhance the possibilities that they too can take advantage of new market prospects.

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6.
Ecological land use planning for sustainable landscapes in Yucatan

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Confronted by the challenges of decreasing biodiversity, depleted natural resources and diminishing quality of life in rural areas resulting from unsustainable development patterns we have attempted to establish strategies for sustainable management of natural resources that are based on participation and commitment of many stakeholders (politicians, scientists, producers and in general society). One such strategy is ecological land use planning for regional development. Environmental planning should be a continuous social effort oriented towards attaining an adequate balance between regional development and natural resource protection. This effort begins with the selection of development and resource use options for the potential use of an area under given constraints of natural processes and ultimately determined by political and economic considerations. Without accurate knowledge of the ecosystems carrying capacities, their natural processes and their simultaneous social usage, additional pressures will be placed on already exploited ecosystems if production activities that depend on existing natural resources are implemented.

This crisis facing Mexico and other countries might be an opportunity to facilitate sustainability, which is not a goal but a dynamic process that requires people participation, capacity building, monitoring the process of change, cultural diversity and globalization, sound governance and institutional changes. An integrated management and a multiple use approach may be a useful strategy which allows coexistence of wild flora and fauna with production. Community-based systems of resource management are of great importance in Mexico. Unfortunately Mexican rural communities are largely poor and have been excluded from the benefits of the country's overall social development. Mexico's natural resources have suffered a dramatic depletion as a consequence of the activities of rural producers. This decline in the quality of the natural resource base is reflected in stagnant agricultural, livestock, forestry, and fisheries production. Mexico is now a net importer of corn, beans, milk and other foodstuffs (Gómez-Pompa, et. al 1993).

The Yucatan Peninsula is located in the most easterly portion of Mexico between 16° 06' and 21° 37' North, and 87^o32' and 90^o23' West. The Peninsula is bordered to the west by the Gulf of Mexico, to the north by the Yucatan Channel, to the east by the Caribbean Sea, and to the South by the State of Tabasco and the Republics of Belize and Guatemala. The Peninsula has between 4.5 and 5 million inhabitants in the three states: Campeche, Yucatan and Quintana Roo. According to recent archaeological studies, this current population is less than the prehispanic Maya population (Turner et al., 2003).

The Peninsula is a large rocky plain of sedimentary limestone, mostly formed during the Tertiary Period, though the northern and eastern edges were formed during the Quaternary. It is the only region in Mexico without a sizable surface hydrology system.

Underground aquifers occur at depths between 3 meters in the North and 120 meters in the South (Lugo-Hubp, et al., 1999). The Yucatan Peninsula has a hot climate with mean annual temperatures between 25 and 28°C. The Northeast of the Peninsula is semi-arid and the remaining areas sub humid. Annual precipitation ranges between 415 and 1690 mm (Orellana, et al., 2003). Vegetation changes according to the precipitation gradient and has a large number of endemic plant species, ranging from Coastal Dune Vegetation to Tropical Rainforest. The region is known for its biodiversity and for its Maya population. Some identified threats due to development are: disturbance of ecological processes, inappropriate waste management, impact of tourism, oil extraction and lack of land use planning.

The Yucatan Peninsula is rapidly being converted from different stages of secondary forest to agriculture and cattle ranching (Table 6.1). An increasing fire frequency within and outside protected reserves is rapidly converting the vast majority of the region to a state of arrested succession (Mizrahi et al. 1997) comprised of young secondary forest with scattered individuals and patches of remaining mature forest. Agricultural development results in a heterogeneous mosaic of varying types of habitat patches across the landscape. These areas constitute an ecological mosaic that includes a great diversity of ecosystems from lands used recently for slash and burn agriculture and cattle grazing activities to secondary vegetation and mature ecosystems.

Ecological land use planning must be done with the involvement of government, scientists, NGOs and producer organizations. The success of the process depends on participation and collaboration of the different stakeholders. The Mexican Government has established a methodology to be followed in ecological land use plans (Table 6.2). Any plan must be registered and approved by the National Institute of Ecology (INE) in order to be considered for financial support. In 2006, the Yucatan State Land Use Plan was published at a general level, and the next step is to develop the land use planning for municipalities since this is the political unit for decision making.

Land use and land cover change, human activities that result in altered land use systems define the environment and socioeconomic sustainability of communities. Since 1992, the Department of Management and Conservation of Natural Resources in the Tropics (PROTROPICO) of the Universidad Autónoma de Yucatán (UADY) has conducted participatory research involving several community groups in the municipality of Hocaba. Although it has been difficult to establish alternative production systems, there have been successes in establishing agroforestry systems, green manuring and cover crops as an alternative for slash and burn agriculture. The long interaction between the community of Hocaba and PROTROPICO has resulted in important basic knowledge such as: a socioeconomic characterization of the municipality and information on soils, vegetation and land use change. In addition, a participatory characterization of the municipality was recently completed (Table 6.2). Ecological land use planning requires the consideration of both traditional and scientific knowledge in order to propose strategies that if supported by Federal and State governments can trigger the development of a sustainable landscape in Yucatan. We here present an overview of how ecological land use planning is being developed together between people from the Hocaba municipality and PROTROPICO, pointing out lessons learned during the process. The initial characterization and diagnostic collected ecological and socioeconomic and

historic information of the region and municipality through different students' thesis, community workshops and literature searches.

Table 6.1. Land use change in Yucatan between 1976 and 2000 (Source: Garcia-Gil 2006)

Land use	1000 ha in 1976	1000 ha in 2000
Agriculture	473	989
Animal production	454	891
Secondary Vegetation	2,058	1,373
Mature Vegetation	1,322	1,015
Urban Areas	5	46
TOTAL	**4,312**	

Table 6.2. Ecological land use planning method used by Mexican government (Source: Arriaga y Córdava, 2006).

Knowledge		
Processes and analytical levels	**Phase**	**Elements of Analysis**
	Negotiation (Workshops)	pre-assessment of local perception on environmental problems
First	Characterization and	natural resources availability and situation productivity and environmental impact of productive systems living standards and social equity levels of sustainability
Second	Diagnostic	available markets migration
Third		impact of institutional policies
	Management	Ecological land use planning by the community
Reality transformation		
Control level	**Phase**	**Factors of Control and Action**
All levels	Prospective	Formulation of scenarios
All levels	Proposal	Ecological land use planning Regional development programs
	Negotiation	Institutional coordination Social agreements Validation of the proposal Environmental log
Third level	Instrumentation	Laws and policies Agreements and coordination Agreements and commitments Environmental log

The Municipality of Hocabá is located in the central region of the state of Yucatan at 20º 49 ' N latitude and 89º 15 ' W longitude within the geomorphologic landscape defined by Lugo-Hubb et al. (1999) as "almost horizontal structural plain along the coast" with up to 10 m of altitude. Hocabá occupies an area of 81.75 km^2, 0.18% of the state (GCEY, 1992). The climate is sub-humid tropical with a summer rain season AW_1(i')g (INEGI, 1995 in refs; Orellana, et al., 2003). The dominant vegetation is low deciduous forest (Flores y Espejel, 1994) and the main land uses are sisal (*Agave fourcroydes* Lem.) production and slash and burn agriculture (Cano, 2000). Two geologic zones converge in this area: a southwest zone with limestone of 13 to 25 million years age (Pliocene-Miocene), cream colour and brownish grey microcrystalline rocks with a large amount of fossils and, in the rest of the area, limestone from 58 million years ago (Eocene) containing fine grained silicates and few fossils (INEGI, 1984).

The principal actors in Hocaba are smallholder households with diverse production activities depending on characteristics of the landscape: soils, vegetation and land tenure. Yucatecan Mayas have a classification for soils and vegetation which is related to both land use history and potential use and which is being considered in land use planning. Land use can alter both the rate and direction of natural processes, and land-use patterns interact with the abiotic template to create the environment in which organisms must live, reproduce, and disperse. Through use strategies of integrated management rather than maximized production per land unit, contemporary Yucatec Maya obtain higher production from the aggregate landscape (Jimenez-Osornio, et al., 2003). This multiple-use strategy is an adaptive response to the heterogeneity of soils, vegetation and land use history.

Maya farmers considered soil colour and topographic position as the first criteria for recognizing soils, followed by other attributes such as stone, rock and gravel content. Farmers distinguish two main groups of soils: *K'ankab* or soils of the plains areas and *Boxlu'um* or soils of mounds (Estrada-Medina, 2000). *K'ankab* is a group of red soils with two variants (*K'ankab* and *Haylu'um*) differentiated by their depth, whereas *Boxlu'um* is a group of dark soils with five variants (*Tsek'el*, *Ch'ich'lu'um*, *Chaltun*, *Puslúum* and *Ch'och'ol*) differentiated by their colour and/or surface stone, gravel and rock contents.

Mayas also have a detailed knowledge of the vegetation which can be correlated with vegetation units described by botanists, which includes space and time as important criteria. Classification of the vegetation is based on previous management, agricultural activity, time of abandonment and size of the trees. Both space and time are important to characterize each forest renewal stage. Nowadays, most of the territory is in secondary vegetation of different ages, all of which are well classified by Maya farmers. There are several terms to identify stages of vegetation renewal. Productive activities are decided according to this knowledge and land tenure.

Hocaba's economy depended on sisal production for several decades, today the main production activities are: slash and burn agriculture, citrus plantations, cattle raising and very few sisal plantations. Of the total of 5,852 ha, 2,259 belong to the ejido (a system of community land sharing), and the rest is private land. In the town of Sahcaba which belongs to this municipality there is a Community reserve which has been used to extract wood (Mizrahi, et al, 1997). Of the 5,312 inhabitants, 25% of households live in extreme poverty, 32% of the families are poor and 43% are non poor families. An

estimated 70% of households are using firewood. Main productive activity is hand labor with 83% of the income that comes from people working in construction, industry and different services and only 7% is dedicated to agricultural activities. Maya milpa (corn production using slash and burn) until recently played an important role for the subsistence of the households which are complemented by home-gardens, citrus plantations, bee-keeping and animal (mainly sheep) production. Today most of the land is a mosaic of secondary vegetation with different ages.

Lessons learned

To examine the factors that influence land use, it is necessary to consider the impact of different production systems, markets, land tenure and government support programs. Slash and burn agriculture increased between 1991 and 1995 mainly due to the governmental program PROCAMPO, which promoted the substitution of slash and burn agriculture by more sustainable agricultural systems. Nevertheless, Maya farmers understood and used the program as a subsidy to continue slash and burn agriculture. Citrus plantations were set up with government support, but no training or advice on management of these plantations was given. As a result most of the irrigation systems are not working and production is low. In future programs it is important to consider local knowledge levels and integrate training and advice to obtain expected results. The collaboration between universities and local governments can be used to improve capacity building while working with real problems and to evaluate the strategies promoted. There is an urgent need for organizations that work as liaisons to facilitate this process.

The economy of the municipality is based on salaried work, men usually work in construction in major cities like Merida, Cancun and Playa del Carmen. Young women work in rural industries (*maquiladoras*) or as domestic workers in the cities. An important recent activity is handicrafts from sisal fibers supported through capacity building and by market opportunities.

Important institutions that can influence land use decisions are households, ejidos, community organizations, markets and conservation programs. *Ejidos* are communal land management councils defined by an area with a collective tenure system and the community that administers and owns it. The municipality has two independent ejidos. Changes in the local governments every three years are a constraint because there is no continuity. Structured land use planning program may solve this problem based on GIS with data from the municipality. It was important to avoid creating unreasonable expectations: locals will ask for any kind of support help, and the purpose of the planning many times is not understood. Advisors should live in the communities to learn about local perceptions and ways of communication. Maya language is obviously a key facilitator. Timing is very important. After a certain period people need to see progress and if not, they may decide to stop collaborating. To overcome this problem, without creating expectations, we started the project *School Homegardens* in one of the technical secondary schools.

The homegarden project has the objective to establish *living laboratories* to improve children education, as well as, to train and promote some agroecological

alternatives for the region. This has been done in collaboration with the Secretaria de Educacion Publica and support from PPD-PNUD, Fundacion Produce Yucatan and The Ford Foundation. In each of the six participant schools there is a committee for decision making in which locals, NGOs, students and the university are involved. The next stage will be to present the project to local government.

Contemporary multiple-use strategies by the Maya of Hocaba imply lower production per land use unit, but higher production of the aggregate landscape, and stands as a dynamic permanent system based on the benefits of diversity. The multiple-use strategy copes with the landscape variety, soil, vegetation and management history, and is an excellent base for the ecological land use planning. Although progress may be slower than expected in the process of ecological land use planning, it is necessary to work with and involve locals in the entire process. The strategy should be open to collaboration by different actors but must be orchestrated through one institution. For the universities and researches, ecological land use planning represents an opportunity and a challenge. The opportunity exists to promote and put into practice scientific knowledge, and to develop different practice-oriented ways of training new professionals. The challenge is to communicate and work with different actors from government officials to producers considering their time horizons and objectives. Establishment of collaborative networks is important to share experience and contribute with regional sustainable development.

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7.

Sustainable development in the context of new ruralities. The case of the Biodiversity Conservation Project in Argentina.

Pablo Rodríguez-Bilella and Esteban Tapella

Ecological knowledge for decision making must include an understanding and analysis of social dimensions. Based on the Biodiversity Conservation Project (PCB – Proyecto de Conservación de la Biodiversidad), which promoted sustainable development in four poor communities in the Central Andes of Argentina, this paper highlights the relevance and importance of looking at transitions and livelihoods in order to understand small farm systems and rural settings in a context of globalization, structural transformations and the emergence of 'new ruralities'.

The concept of 'new ruralities' refers to the new, developing organizational forms and agrarian structures for combining natural resources, labour and capital. The global agro-food regime that emerged with the expansion of the market oriented economy since the nineties and the increasing concentration of land and economic control with agro-industrial corporations initiated a process of rural transformation which has been called 'new ruralities' in Latin America (for details see Teubal 2002, Echeverría 2000 and Arce 1999). Part of this process has been the 'disappearing peasantry' (Bryceson et al. 2000): small farmers have reduced their participation in the economy as large producers, agricultural corporations and investors concentrate land use and economic power.

However, the macro-vision of these transformations does not help us to understand how people weave their way through, make sense of and live out such structural transformations. The PCB is an opportunity to analyze not only the different types of farmers and productive strategies (synchronic analysis) but also the trajectories of transformation (diachronic analysis).

A case study of two decades of structural change in Argentina

In the past two decades there have been dramatic changes in Argentinean rural societies. Structural adjustment programmes, the expansion of transnational corporations (TNCs) and the integration of agriculture into global agro-industrial markets, have transformed the agricultural sector, resulting in a new division of labour (Tapella 2004, 2005). On the one hand, large commercial farmers and TNCs became involved in finance, production and marketing of the agro-industrial process, increasing output with advanced technologies and intensive use of chemicals, and reducing labour costs through contract-farming schemes. On the other hand, many peasants were marginalised or asymmetrically included. They could not participate in contract farming and vertical integration, limiting their role to one of providing cheap food and labour. As a consequence, modernisation resulted in more concentration of capital and a more inequitable distribution of wealth.

From a macro economic point of view, Argentina experienced a major evolution of the agricultural sector in terms of new technologies, increased production and exportation. Continuing agricultural growth has maintained the contribution of the primary and agro-industrial sector near 30 per cent of GNP (Lattuada, 2000:2-6). However, participation of the peasantry in the economy decreased, open competition produced unequal growth with some regions becoming more viable than others, and rural poverty increased (Maletta, 1995). Rural unemployment reached 31 per cent in 1999 (Hicks, 2000:17). The last census (INDEC, 2003) indicated that Argentina experienced an increase in agriculture production together with a shrinkage of the small farm sector: the number of farmers in Argentina decreased 24.4 per cent in 15 years. This process was accompanied by a concentration of production and land tenure. The amount of land per farmer increased 28 per cent, without opening new agricultural lands. Land is being concentrated in large operations in highly mechanized systems often with genetically modified crops that support minimum tillage regimes (Gwynne & Kay, 1999 and 2004). A significant agrarian transition has followed these changes (Kay 1994, 1995 and 2000; Gwynne & Kay, 1999 and 2004; and Echeverría 2000). Many small farmers now provide labour to rural and urban labour markets under employment conditions that are precarious, temporary and 'flexible'. At the same time, development policies have shifted from state intervention towards Social Funds or rural development programs. In Argentina, state intervention in the rural sector during and after structural reforms shows different objectives (Manzanal, 2000:92). Governments have implemented policies aimed at increasing export-oriented agricultural production and re-activating the economy. Many small producers could not compete in this scenario and abandoned their land to sell their labour or migrate to the urban sector. Argentina has implemented different Social Funds to mitigate the impact of structural adjustment and reduce poverty, mainly targeting different 'types' of producers and rural poor. There are examples of Social Funds in agriculture, primary education, health, family planning, natural resources, rural infrastructure, urban shelter, water and sanitation (Narayan and Ebbe, 1997). However, not all stakeholders and communities fit into these broad trends. There is a need for a more detailed analysis of the dynamics of people's livelihood in order to understand small farm systems and their trajectories (Rodríguez Bilella and Tapella, 2008).

The Biodiversity Conservation Project (PCB) and the San Guillermo National Park, San Juan, Argentina.

The PCB was implemented by the National Parks Administration, being mainly financed by the Global Environmental Facility (GEF) of the World Bank. The general goal of the project was to conserve particular areas with biodiversity of global importance. The specific objectives were to: (a) expand and diversify the existing protected areas including several of the country's most globally significant but inadequately protected eco-regions, (b) create conditions for their sustainable management through investing in institutional strengthening, refined mechanism of consultation and participation, and improved biodiversity information management, and (c) support sustainable development projects run by local actors living in the buffer zones of protected areas (GEF, 1997).

Because of Argentina's wide latitudinal, altitudinal and climatic range, the country is rich in ecological regions and biological diversity. Argentina has long recognized the importance of these biological resources, and its national park system is the first in Latin America. Argentina's national park system represents an important economic resource, with major tourist attractions that provide significant sources of revenue. On the other hand, a recent National Parks Administration analysis estimated that only 21 % of the protected areas is adequately managed, 30 % is under some form of management, and almost 50 % cent receive very little or no management . Importantly, most of the population living in buffer zones or within protected areas has never been involved in sustainable development projects; so the use of natural resources in those areas are not always rational and often have negative impacts on its biodiversity (Bucher et al, 1996).

The San Guillermo National Park of 150,000 hectares is at approximately 3500 m a.s.l. within the San Guillermo Biosphere Reserve, which has a surface of 996,000 hectares. It was created in 1998 to contribute to the conservation of the highest concentration of vicuña in South America, but also to protect the cultural and historical heritage of the pre-Hispanic population which occupied the area 8.500 years ago. The PCB project had two main fields of action: (a) biodiversity conservation activities concerning the protected area, and (b) sustainable development projects that focus on local actors living in the buffer zones. Sustainable Development Activities in Buffer Zones were aimed at supporting improved community land use practices through pilot projects, applied studies, and extension and training activities. Pilot activities consisted in funding a variety of small scale projects such as testing improved land management options, organic agriculture, honey production, rural tourism and handicraft production, recovery of depredated natural grasslands, fire management, and the implementation of complementary biodiversity studies that would contribute to the sustainable use and conservation of biodiversity in national parks and buffer zones (GEF, 1997).

The project adopted some of the characteristics of Social Funds, and interventions emphasized collaboration between the public, private and NGO sectors. There was a process of debate among local stakeholders and different institutions linked to the area in order to re-think previous assumptions and expectations. The complex equilibrium between sustainable development and conservation was put in the context of structural changes and the increase of rural poverty during the last two decades. These types of interventions often face a 'trade-off' between natural resource sustainability and poverty reduction. It is believed, that the more programs focus on poverty alleviation (and usually people living in the buffer zones are poor), the more difficult it is to achieve natural resource sustainability. The stricter the control on use and conservation of resources, the more institutions tend to 'exclude' the poorest land users since the opportunities for alternative production are narrower. How to overcome this conflict and link these objectives is the core issue for any intervention in this field.

It was decided that the GEF would support production oriented projects only when they fulfil the following requirements: (a) activities should protect and conserve basic resources, land, soil, water, air, etc.; (b) projects should be aimed at satisfying basic needs and reduce rural poverty; and (c) projects should not only be technically feasible, but also economically sustainable, since beneficiaries will have to cover project costs in future productive cycles (APN, 2006). The project was implemented in four Andean

communities in the buffer zone of San Guillermo National Park, at 2,000 m a.s.l.. The communities are in micro irrigated oases with agriculture, forest, fruit and cattle production.

A Rapid Rural Appraisal in 2003 characterized social, cultural and productive aspects of local communities, like demography, dynamics of productive systems, income sources, housing, education and health conditions, etc., using a socio-economic household survey on 75 per cent of the population, a participatory rural appraisal workshop and many unstructured interviews. A social typology was constructed based on different combinations of household's assets, mainly 'produced' and 'natural' capital. The study also characterized the institutional capacity to provide technical assistance to beneficiaries and support production and training projects designed to local expectations and needs.

Different types of institutions were invited to participate in the program: NGOs connected with rural development projects, honey production and environmental issues; different departments of the National University of San Juan; local civil society organizations; different departments and ministries of the provincial government of San Juan; National Institute of Water (INA), and the National Institute for Agriculture and Technology (INTA), among others. INTA and a bee-keeper NGO attended 75 per cent of total beneficiaries (nearly 150 households), organized in 8 distinct agricultural, honey, cattle and milk productivon projects for subsistence and the local market.

The social typology built up in the rapid rural appraisal was thought to be a way of adapting the external intervention to the highly heterogeneous local context of the buffer zone of San Guillermo National Park. Six social types were identified, three of which were the most relevant in terms of population and project beneficiaries (Tapella, 2003):

1. Small farmers, whose main income comes from arable or cattle farming and handicrafts. They produce for subsitence and local market, usually with family labour.
2. Salaried small farmers have similar characteristics to (1), but in addition have an income from jobs as civil servants (municipality, local police, irrigation district, etc.).
3. Unemployed rural poor who, although they usually have access to land, are not farmers but are occasionally hired as farm and non-farm labour, often obtaining their income from the collection and sale of firewood, or from odd jobs.

The present analysis was made eighteen months after the project began, involving interviews with different stakeholders, participant observation, and life history interviews (Francis 1992). Particular attention was paid to assessing the relevance of micro-projects in helping people to increase income or household consumption, the degree to which people had a sense of "ownership" of their project and had adopted (at least partially) new technologies, and the way the project impact differed according to distinct social types of farmers and different households' trajectories within the same social type.

The first conclusion that can be drawn from the experience is that besides differentiating local actors according to their physical capital, they should also be analysed according to cultural and social assets and the ways in which they combine these assets during the development trajectories. Micro-projects were successful for both

small farmers and salaried small farmers, and many projects went beyond their original objectives. Most of these farmers had no access to technical advice, while market conditions had reduced their production opportunities. Farmers adopted most of the technologies suggested, made good use of their investments, and eagerly demanded attention from the extension workers. They in fact received most of the extension workers´ attention, as it was easier and rewarding for them to work with these farmers than with other members of the communities. In contrast, the results among the unemployed rural poor were quite heterogeneous, despite the groups apparent homogeneity with similar income sources, capital assets and poverty level. While some of the households replicated the success of the small farmers´ projects, others failed to give a good use of the investments, showed apathy towards the extension workers, and did not have a sense of ownership over their micro-project.

An analysis of the life-trajectories of the unemployed rural poor was necessary in order to better understand those contrasting results. The analysis revealed two different sub-groups among the unemployed, who differed in their socio-cultural background. In most cases where the project succeeded, participants expressed their joy of returning to production as (very) small farmers, improve infrastructure for animals (yards, watering troughs) and start to tend pastures trees, small orchards, etc. For these actors, the project intervention reinforced and reshaped many of their goals, perceptions and values, making a link with their former experience as small farmers. This shows that livelihoods should be viewed not just as a matter of material well-being but also of non-material aspects. Beyond the availability of produced or natural assets, consideration of cultural, social and human trajectories and capital will help policy makers and rural extensionits understand heterogeneous development potentials in rural livelihoods.

A possible conclusion is that the intervention should have focused on current or former farm households since they have a greater possibility of taking advantage of the intervention strategy. However, this would mean reinforcing the limitations of intervention by attending just a few families, since less than 10% of the rural labourer households have an agrarian background, and less than 38% of the total population are small farmers (salaried or not). The constructed typologies used essentially fixed households in static categories without considering life trajectories and how livelihoods depend on a wide range of assets related to natural, human or social capital (Bebbington 1999). This could be worked differently by understanding the experiential dimension of poverty and livelihood issues as well as issues of social heterogeneity and cultural diversity. A more 'inclusive' alternative would be to include off-farm and non-agricultural activities in rural development projects. The sustainable livelihood approach can be an effective tool to include such complexities (Rodríguez Bilella y Tapella, 2008). It can enrich both research and rural extension, sustainable development and environmental projects.

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8.

Impacts of land use change on ecosystems and society in the Rio de La Plata basin

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The La Plata river basin (LPB) covers an area of 3.1 million km^2 with a population of over 100 million people of Argentina, Bolivia, Brazil, Paraguay, and Uruguay. The LPB covers a wide geographical area, spanning a South to North latitudinal gradient, resulting in the establishment of a variety of soil - vegetation configurations, as a response to different climates. The inherent topographic heterogeneity of the LPB adds natural complexity to the basin, resulting in a combination of extensive savannah-like plateaus (cerrado) and grasslands and open fields (pampas) in its Northern and Southern portions, respectively, the largest tropical wetland area in the world in the Northwest (pantanal), as well as both dry and humid forest biomes (chaco and Atlantic forests, respectively). This varied composition of biomes and ecosystems, added to the different social and cultural setup of the LPB, resulted in diverse histories and complex patterns of land use in the basin.

Rural land use and industry in the basin are responsible for 70% of the Gross National Products of the LPB countries and are in a process of continuous change, as a response to drivers such as international market trends, infra-structure and technology developments, societal evolution, and the dynamics of national policies. Possible land use changes (LUC) are limited by biophysical constraints such as unsuitable soil type, topography, or climate. However, technology development can overcome some of these limitations, as was the case of the soybean expansion to the Cerrado region of Brazil, in the eighties.

Effective and sustainable management of the LPB depends on the ability of land managers from the five nations to predict the impacts LUCs on nature and society. Modeling efforts to predict environmental impacts in the LPB can benefit from knowledge acquired from impact assessments of major LUC processes. Land use change affects both the natural environment and society, therefore impact indicators should represent both dimensions. The human and natural dimensions interact both as drivers and as recipients of the impacts of LUC. The altered state of the impacted human and natural dimensions will reconfigure them as altered LUC drivers. Understanding these feedback mechanisms is a great challenge that integrates natural and social sciences. There is an urgent need for interdisciplinary research, overcoming inherent conceptual and epistemologic barriers. Decision makers and society will only act on response to global change science results, when social and natural scientists achieve an effective integrated research framework.

Land use change in the LPB

Three agricultural sectors have been responsible for most of the LUC in the LPB in the last thirty years: international commodities (soybeans, etc.), forestry (eucalypt and pine), and meat (cattle). Soybean and other grain crops, as well as cultivated pasture (Brachiaria spp.) are widespread in the LPB, and have replaced portions of all of the basin´s biomes. Forestry has been concentrated in the Southern portion of the basin. Biofuel crops, such as sugarcane, are increasing as a result of the growing international market, and national policies. Impacts of LUC processes will vary according to the biophysical and social configurations of the altered sites. During the last 30 years massive changes have occurred in the whole basin, with significant impacts both to nature and society.

Land use changes in Brazil

Agricultural use of the land has expanded 100 million ha during the last 40 years, with an average 3 million ha/year in Brazil (Filoso et al., 2006). Most of this expansion was caused by increases in pasture lands, although during the last 10 years cropland expansion has been greater (Alves et al., 2003). Much of this expansion has been over Cerrado land. The Cerrado covers about 2 million km^2 and contains the headwaters of the Parana and Paraguay river sub-basins, components of the La Plata river basin. The Cerrado is a complex environment, with different types of vegetation formations. They vary mainly with soil type and water availability (water table depth). Several authors suggest that the Cerrado is being destroyed for grain crops and pastures (Klink and Moreira, 2002; Fearnside, 2001). Estimates vary from 40 to 50% of the Cerrado already having undergone complete destruction (Joly et al., 1999; Alho and Souza Martins, 1995). Jepson (2005) argues that regeneration rates of Cerrado vegetation are very high, and that this may render this biome particularly resilient, enabling its recovery if appropriate land management strategies are adopted.

The seventies were characterized by agriculture expansion to the cerrado biome, driven by incentives of the Brazilian Federal Government as well as multilateral funding agencies. Scientific and technological development enabled the agricultural occupation of the Cerrado, correcting the high acidity and low fertility of its soils, and also adapting soybean varieties to the Cerrado environment. In 15 years, 14.1 million ha of Cerrado vegetation were converted to agro-pastoral use with potential impacts to nature and society (Pinto, 2002). More recent data, compiled from the Instituto Brasileiro de Geografia (IBGE) website, show that the expansion continues in the region, with a remarkable of growth of the soybean planted area in the State of Mato Grosso, from 1990 to 2005. In 1997, 52% of the soybean, 34% of the rice, 26% of the maize, 21% of the coffee, and 41% of the cattle meat produced in Brazil came from the Cerrado (IGBE). Likewise, the convertion of Cerrado ecosystems into cultivated pastures, most of it African grasses of the genus Brachiaria, has shown a steady growth rate during the last 3 decades. Macedo (1996) estimated that 45 to 50 million ha of the Cerrado were occupied with pastures at the second half of the nineties.

Land use changes in Argentina

Agricultural intensification has occurred throughout the Pampas in all ecosystem types, with a predominance of cash crops, often doubled, and the abandoning of the traditional mixed agriculture-livestock production system. Higher gains through grain and oilseed production, low beef prices and reduced markets for beef, as well as the exceptionally high agricultural suitability of the La Plata basin lands drove farmers into more intensive agricultural land use. The introduction of direct seeding or zero tillage favored this trend, since maintaining a reasonable level of soil cover helps to prevent erosion and thus minimizes the visible impact of agricultural intensification.

Expansion of the agricultural frontier takes place in marginal areas such as the semiarid "Espinal" savannah and in the flooded plains of Buenos Aires. In these biomes natural vegetation traditionally used for extensive livestock production is replaced by cash crops, mainly oilseeds such as soybean and sunflower varieties that are adapted to these environments. Advances in genetics and other technological developments that improve the feasibility of cash crops in marginal lands accelerated the clearing of savannahs in all sub-humid to semiarid environments and the appearance of vast cultivated areas in former rangelands.

Impacts of LUC on ecosystems

The most severe impacts of land use change on soil resources are: depletion of soil organic matter, and consequent loss of fertility and reduction of carbon stocks; erosion and desertification; and biological degradation. Water resources suffers degradation of quality, through agrochemical contamination, increases in the organic load, increase in sediment transport and siltation, increase in the amplitude between river flow upper and lower limits along the year, increasing damages caused by flooding events and dry spells (water shortages).

Impacts on ecosystem functions in Brazil

Cerrado conversion to cropland results in reduction of soil organic matter content, aggregation stability indices, and biological activity and diversity (Madari et al., 2005; Peixoto et al., 2006; Green et al., 2007). Although the adoption of no tillage practices reduces those effects on soil quality, the impacts of land use change in the Cerrado are highly significant. Soil organic carbon content in the 0- to 5-cm layer was reduced to approximately 30% of its original status in a experimental site under continuous cultivation for 20 years (Green et al., 2007). Peixoto and colleagues (2006) have shown the significant negative impact of agriculture on soil bacteria and on soil aggregation. This results in lower soil water holding capacities and water infiltration rates. Erosion is probably the most severe negative impact of land use change in the Cerrado, especially in the northern portion of the Paraguay river basin.

Impacts to the quality of water resources are also a problem. In Brazil, the Water Resource National Policy (Brazilian Law 009433-1997) has improved the management

mechanisms by the creation of River Basin Committees which have the power to decide upon rights and obligations of water users, and to charge taxes depending on how much water is used, and on how the water quality is affected by users. So far, only one river basin of Brazil has applied most of the legal instruments predicted by the National Policy, the Paraíba do Sul river basin, in the Brazilian Southeast. The result has been greater participation of society in decision making, and a slight improvement in the awareness of industry and urban managers regarding environmental problems, mostly related to point source pollution. But a greater problem is non-point source pollution, such as agrochemicals, including pesticides and fertilizers.

Deforestation for crops or pastures results in increased N mineralization and mobilization, with subsequent higher N transport by streams (Williams and Melack, 1997; Neill et al., 1997). The Cerrado ecosystem needs substantial amounts of fertilizer inputs and liming to become productive as croplands. Land use changes in the basin have been indicated as responsible for observed changes in phosphorous concentrations and depositions due to change in pH, increase in sediment content due to erosion, and increased nitrogen exports in the water (Villar et al., 1998).

Researchers have produced a lot of data on carbon and nitrogen in agroecosystems. The natural ecosystems, that are being continuously degraded and destroyed, were the subject of much less research efforts. Some urgent questions to be answered are: What are the rates of biological nitrogen fixation in tropical natural ecosystems? How do they compare to those observed in agricultural ecosystems? How do changes in the N cycle affect plant metabolism, phenology, primary productivity of ecosystems, and the global carbon cycle? How do they affect the local, regional, and global climate? What are the feedbacks?

Impacts on ecosystem functions in Argentina

Semiarid soils in Argentina show losses of 22% of original pasture C after only two years of cropping. Biological activity, both microbial (Frank et al., 2004; Noellemeyer et al., 2008,) and faunal (Glizzi et al., 2006), is decreased under prolonged agricultural unless pasture is included in rotations (Eiza et al. 2006) to compensate for the C losses under cultivation. The degradation of soils with long agricultural history without pasture rotations results in higher susceptibility for wind and water erosion, lower water availability due to lower infiltration and water retention and susceptibility to compaction. This results in lower crop productivity (Quiroga et al., 2006; Funaro et al., 2006; Funaro et al., 2005) and thus directly affects farmer income and regional economy. Zach et al. (2006) showed that in the coarse texture illitic soils of the semiarid Pampa potentially irreversible soil degradation can occur after prolonged intensive cultivation. Soil carbon in these soils is less stable than that of more humid grasslands, with very rapid turnover rates (half lives of 10-16 years) and reduced capacity for C stabilization. Valuable resources are being degraded, perhaps to an extent where the thresholds of resilience are exceeded and no or very little chances of restoration are left. C accretion in soils under restoration (pastures) may be rapid, but leveled off well below original C levels.

Management practices that have shown to prevent excessive degradation are rotations with perennial pastures and cash crop intervals that depend on climate, soil

parent material and texture and the type of crops that are used. A return to such conservative soil management is difficult to reconcile with the objectives of farmers and corporations that take land use decisions for profit maximization in the short term. Nevertheless, some farmer's organizations (CREA) have recognized that extended oilseed monocultures caused compaction and run-off which decreased crop yields in the sub-humid and semiarid region. This showed that an adequate C balance cannot even be achieved under zero tillage without rotations with pastures.

Economic changes in the agricultural system of Argentina

One of the most concerning trends of land tenure in the Argentinean Pampas is the concentration of agricultural lands and ownership by corporations. Questions that arise in the context of LUC, agricultural intensification and land degradation are: How do LUC processes affect the farmer's social environment and rural population in general? How is the land-owner connected to his land? And in which social context does he take decisions?

The 2002 agricultural census reveals some important developments that characterize the rural population and the social environment of farmers / land owners: the traditional concept of "family farms" that prevailed in the Argentinean rural environment is changing. Farm residents are now increasingly paid labor. Only in regions like Catamarca, where very low technology is common, family labor is more important than hired labor. What are the implications of this development for resource management? If increasing number of farmers literally live "off" their land and their families are firmly established in an urban lifestyle? Under these circumstances, can the land be considered a heritage to be conserved for future generations? Or is the land only one of the capital resources that produces the required income?

If this scenario of increasingly industrialized agricultural production and disappearance of family farms is considered the framework for future land use change, it becomes clear that the current trends of agricultural intensification and expansion will continue. The associated social costs of land degradation will have to be mitigated through policies that take into account the socio economic characteristics of the new "rurality", specifically the decision makers of this newly emerging agricultural system, which in many cases are not the land owners but managers of financial and commercial corporations.

Integrated tools for land use change impact assessment

A central obstacle to understanding, predicting, and assessing the interactions between human and natural systems that govern LUC in heterogeneous landscapes is the lack of a comprehensive and integrated research framework capable of addressing the inherent complexity of the system (Vitousek et al. 1997). It is a big challenge to the scientific community to deliver innovative concepts, methodologies and tools to help society cope with the uncertainties posed by current trends of global environmental degradation. Computer-based and spatially explicit simulation models could be useful to inform

decision makers about scenarios of land use change and their potential ecological and social consequences. Models like these require extensive data bases and implementation efforts. Several spatially explicit models have been developed to simulate land use changes, based mainly on biophysical potentials. An improvement was the development of models (Kerr et al. 2003) that explored possible changes in land use as a function of driving forces other than biophysics. Verburg et al. (1999) included a multi-scale approach into what they called the Conversion of Land Use and its Effects (CLUE) modeling framework. However, little attention has been paid to the human behavioral component driving the changes (Irwin and Geoghegan 2001), and research has been particularly lacking regarding the spatial and temporal scales across which the social component interacts with the biophysical component. Further development of simulation models, which better account for the human aspects of LUC, is necessary for improving research frameworks on the interactions of ecosystems and humans.

Since 2002, a network of scientists across the Americas has been discussing these issues under the guidance of the American Association for the Advancement of Science (AAAS), through its Ecosystem Dynamics and Essential Human Needs (EDEHN) program. The outcome was the development of a conceptual framework, that depicts land use change drivers and impacts, their cross-scale interactions, as well as possible feedback mechanisms. This network evolved into a larger group of researchers and Institutions to develop a IAI research network on "Land use change in the Rio de La Plata basin".

Integrated soil and hydrological monitoring will be applied to the watersheds, so that data will inform decision makers about the effects of LUCs on the carbon dynamics, as well as on water quality and quantity. On a regional scale, ecosystem functioning will be evaluated through measurements of evapotranspiration and primary productivity by remote sensing. Knowledge on land use patterns and their biophysical and socio-economic characteristics will allow the development of models to predict impacts across the scales, from individual watersheds to the la Plata river basin, days to years, and from society to nature.

Conclusion

Natural sciences have produced a wealth of data demonstrating the effects of different types of land use change on ecosystems variables, such as nutrient cycling parameters, conservation status of biodiversity, hydrological disturbances, soil and water quality degradation, contamination, climate change, among others. However, although some more informed sectors of society react by slightly changing their consumption patterns and by supporting public pressure campaigns directed at policy makers, in general there is very little response from society.

As computer technology and the global electronic network places information at a grasping distance from any school student, global change scientists face the challenge of generating research results that are at the same time of high scientific standard, and also seen as of practical value by society. Effective inter-disciplinary research connecting natural and social sciences, based on a common conceptual ground, may help to bridge the current gap, and generate scientific results that effectively inform decision making.

Model development should rely on participatory methods from their start. Policy makers should inform scientists about requirements for knowledge and models. An example of an inter-disciplinary participatory experience is the SENSOR Project, coordinated by ZALF (Germany), and carried out by 33 institutions of 15 European countries (http://www.sensor-ip.org/). This project is the result of a demand from the European Commission for a tool to help them assess the economic, social and environmental impacts of multifunctional land use in Europe. The model and computational tool being developed is tailor-made according to the needs of policy makers. It is expected that the end product will be directly applicable by society, through its legislators, and is developed based on high quality scientific knowledge. An extension of the Sensor project to Brazil, Argentina and Uruguay will assess the transferability of the methodology to the LUC conditions prevalent in the La plata basin. The main challenge will be to achieve an interaction between scientists and policy makers in the Mercosur countries.

The huge challenges posed by the dynamics of LUC in the La Plata basin as well as their impacts demand innovative and integrative procedures and attitudes from both natural and social scientists, as well as from decision makers. The advance of global change processes demands a quick response from society. Measuring and modeling ecosystem services of natural and modified environments, as well as estimating their economic value, is essential. Transforming this knowledge in effective changes of sociological behaviour is crucial.

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9.
Environmental winners and losers in Argentina's soybean boom

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In 1991, Argentina launched its "convertibility plan" with the aim of reducing rampant inflation and stabilizing its economy. The plan included a deregulation of the country's economy: tariffs were lowered and export taxes (temporarily) eliminated. These reforms had major structural effects on the agricultural sector, the price of inputs (goods and services) increased relative to the price of produced commodities. Development strategies based on cost reduction and economies of scale were favored, resulting in an expansion of no-till genetically modified soybean, and a considerable increase in the size of land-holdings. This modernization process was the dominant adaptation strategy by farmers and received considerable support from governmental extension services that provided technological packages for soybean cultivation for example.

Together with improved rainfall and high prices, these economic changes resulted in a "soybean boom" that has made Argentina the world's third soybean producer with more than 13 million ha under cultivation (Grau et al., 2005, Zak et al*., 2008)*. Although it has undoubtedly brought benefits in terms of increased exports and regional wealth generation, the soybean boom and its agro-industrial development model has also come at a cost: not all farmers were able to follow the development model, thus contributing to land concentration; farm workers lost employment opportunities as labor-intensive crops and animal husbandry disappeared; small-holders and peasants were displaced, losing access to ecosystem services; and increasing pesticide use has brought health problems to rural communities. In spite of the overwhelming dominance of the agro-industrial model, alternative adaptation strategies were possible. In this paper we investigate these alternatives – their economic viability and environmental sustainability.

Case study: Reconquista, Santa Fé province, Argentina

The case-study area covers 7264 Km^2 with a population of 120,000 people around the city of Reconquista, in the North of Santa Fe province. The study area corresponds to the operational area of the *Asociación para el Desarollo Regional de Reconquista* (ADR). ADR is a local non-governmental organization (NGO) with the aims to foster economic and cultural development in the region, and to provide extension services. By setting the stage for other local organizations and stakeholder groups involved in the region's development, the ADR is an important institutional innovation in the region. Nevertheless, it has not improved the political representation of the most marginalized sectors of society in the region.

Within Argentina, the region can be considered as marginal: it is dependant on markets and service centers located outside the region reached only by a poor road network. Most of the region's soils are not suitable for intensive agriculture and the

region is home to the majority of the province's rural poor. In the western plains, soils are poor and fragile. In the eastern flood-plain, frequent flooding prevents annual crop cultivation. Only the *Domo Oriental* (below) is extensively cultivated.

Ecosystems and their uses

The Paraná River borders the region to the East and also sets the eastern limit of Argentina's *Chaco húmedo* ecosystem. The Paraná floodplain is a distinctive environment of regularly flooded plains, rivers and lakes and dispersed wooded islands. Low human impact by essentially semi-nomadic grazing are associated with high plant and animal diversity (Canevari et al., 1998, Malvarez, 2004). A number of ecosystem products such as game, honey, fuel-wood, or fish are used by local communities. The floodplain is considered a priority area for conservation at regional and even international level (Jaaukanigás RAMSAR Convention site).

To the West of the region lies the *Cuña boscosa* plain, covered by deciduous *chaco oriental* forests (Cabrera, 1976, Lewis & Pire, 1981) of around 360.000 ha with quebracho colorado (*Schinopsis balansae*), quebracho blanco (*Aspidosperma quebracho-blanco*) and algarrobos (*Prosopis* spp.) being the dominant tree species. Because of poor and fragile soils, the area has traditionally been used for raising livestock and extracting timber, fuel-wood and charcoal. Shrubs cover areas which have undergone selective logging and are heavily grazed. Some areas have saline soils.

The *Cuña boscosa* plains rise eastward towards the *Domo oriental*, before the lower-lying Paraná floodplain. The *Domo oriental* follows the main N-S road through the region and is home to most of its inhabitants. Having the best agricultural soils, it has been extensively cultivated since the beginning of the 20th century. Mixed livestock and crop systems (cotton, linen, sorghum, corn and sunflower) resulted in a diversified agricultural landscape with small parcels separated by hedgerows and small woodland patches (with typical oriental Chaco tree species). During the last quarter of a century, these systems have been replaced by monocultures: sunflower and more recently soybean. The increasing size of land-holdings is also associated with the loss of field margins and small woodland areas, reducing overall landscape diversity.

Livestock still occupies the greater part of the area, especially in the *Cuña boscosa* and Paraná floodplain, and generates about half the income. Soybean has spread through a replacement of previous crops rather than through deforestation or conversion of natural ecosystems into cropland (as occurs in other areas of Argentina and South America, Grau et al., 2005).

Adaptation strategies

In exploring the diverse adaptation strategies used by rural producers in adapting (or not) to the changing socio-economic context of agriculture in the 1990s, we consider two major production models: the dominant agro-industrial model largely based on GM soybean, and an agro-ecological model illustrated by self-sufficient "peasant" systems.

The dominant agro-industrial model

Farmers that already had available capital at the onset of the 1990's reforms were the most involved in the spread of the dominant agro-industrial model. Small-holders who followed this pathway generally were unsuccessful. Within the agro-industrial model, successful farmers are those that adopted the whole technological package offered. They concentrated on increasing yields and specializing in their most profitable cropping system, following the example of farmers in more favorable regions of the humid Pampa. However, being located in more marginal environments for intensive agriculture, the production systems they developed tend to be less resilient and more sensitive to inter-annual variability.

Not all commercial farmers were successful in adopting the new technological packages. The economic context of the 1990s led a number of farmers into a process of decapitalization. Many such farmers invested heavily into modernizing their equipment but could not service their rising debt and were forced to sell their assets. Their land was generally rented or bought by more successful commercial farmers, contributing to land concentration in the area. The situation of these decapitalized farmers is dramatic as they are not economically viable (their equipment and/or land do not allow them to be competitive), yet they are not able to benefit from the government's social programs for the rural poor, nor do they have a cultural predisposition for it.

Some small-holders have also taken up the agro-industrial development pathway. Unable to invest in adequate machinery and without land to benefit from economies of scale, small holders base their production systems on family workforce. Many are specialized in fruit and vegetables, providing urban areas with a variety of fresh produce (from peri-urban locations) or specializing in a limited number of crops for the regional and national markets (e.g., strawberries in Coronda). The soy boom was associated with rising land prices, and many indebted small-holders took this opportunity to sell their land and leave farming. Others, under less financial pressure, now rent their land.

The agro-ecological model

Small-holder production systems that are not integrated into the agro-industrial chain follow subsistence objectives, relying heavily on sustaining agricultural production with minimum external inputs. We chose to label this alternative model "agro-ecological" (Altieri, 1995a & 1995b). The majority of alternative small-holder systems in Santa Fe province are located in the more marginal areas of the *Cuña boscosa* and Paraná floodplain. They are usually not targeted by government or agri-business modernization efforts. Rather, they benefit from a diverse set of public and NGO assistance and rural development programs such as the "Programa Social Agropecuario" (PSA), a national government program that was in part designed to facilitate the adaptation of the rural poor to the 1990s reforms and support rural development through loans.

Rather than imposing a common development model, programs such as PSA develop bottom-up approaches through participatory work with farmer groups to identify locally suitable development opportunities. Most of these aim at diversification of

production (including crops, milk and meat), value-added activities (including jams, preserves, cheese, traditional medicines etc.) and marketing.

In the study area, the agro-ecological model has also inspired a group of capitalized farmers who have developed economically viable "biological" agricultural production systems (Altieri, 1995a & 1995b, Koepf et al., 1976). One example is the "*Naturaleza Viva*" farm started in 1991 and which today produces more than 150 types of agricultural products, on 220 ha (a small area for commercial agriculture by Argentinean standards). Some of these are processed on the farm using modern industrial processes (yogurts, cheese, vegetable oils, flours, jams and meats) and sold at markets. The farm's production system is centered on the idea of recreating a traditional agricultural system that incorporates recent scientific knowledge and know-how. It combines high plant and animal diversity in order to foster inter-species complementarities and biological pest-control (no agro-chemicals are used on the farm), with special attention to maintaining soil quality and fertility. Although initially a family-run business, the farm now employs personnel (a total 11 families currently live on the farm), and is rapidly expanding, both horizontally (coordinating production with other producers in the area) and vertically (a processing unit for organic products is being built).

Winners and losers

Effective adaptation strategies to 1990s reforms were developed both within the dominant model and the alternative agro-ecological model (e.g., *Naturaleza Viva*). The agro-industrial model is largely dominant in terms of area and production, and its success is well documented, particularly in the context of Argentina's recovery from the 2001 financial crisis. However, successful agro-ecological producers are also rapidly developing as the markets for organic and 'natural' products develop, both nationally and internationally. Both types of producers, but especially those that followed the dominant model, are often considered the winners of the 1990s reforms, and for many, the post-2001 situation has brought immense benefits through lower domestic costs and high export prices.

Stakeholder interviews in the Reconquista area showed that ineffective production systems can be found within both models explored here. Some operations are not economically viable (e.g., farmer decapitalization and small labor-intensive strategies) or remain dependant on outside intervention (e.g., peasant farmers in PSA programs). These are the losers of the 1990s reforms. Other losers include temporary rural workers who lost many employment opportunities as cotton and sugar-cane were replaced by annual crops with heavily mechanized harvesting (e.g., wheat and soybean) and also lost protective social laws to labor market reforms. Former rural workers and people of indigenous descent now form the most vulnerable components of society, seeking out a living on the periphery of the region's towns and cities. As in many areas of Argentina and South America, structural reforms in the 1990s and the expansion of the agro-industrial model the intensification of annual crop production in ever bigger land-holdings has also had major impacts on the region's environment.

Environmental impacts

Environmental impacts of agricultural intensification and homogenization in the *Domo oriental* have also been felt in the adjacent *Cuña boscosa* plains (to the West) and Paraná floodplain (to the East) through the displacement of pastoral activities and agro-chemical transfers.

Ecosystem services

Changing land use patterns and practices can affect the delivery of ecosystem services (Daily, 1997) by modifying both the structure and functioning of ecosystems (Chapin et al., 2000) and agro-ecosystems (Foley et al., 2005). The Millennium Assessment defines four main categories of services provided by ecosystems (Millenium Ecosystem Assessment 2005):

> *Provisioning services* are the material benefits people gain from ecosystems, such as food and fiber, fuel and timber, genetic resources for crop improvement and medicine, natural chemicals and water.
> *Regulating services* are the benefits people gain from ecosystem processes that sustain different components of Human well-being. Examples include crop pollination, ecosystem resistance to invasion by exotic species, climate and atmospheric chemistry regulation, pest control, water purification and erosion control.
> *Cultural services* are the intangible benefits people obtain from ecosystem through their contribution to such things as education and science, spiritual fulfillment, aesthetic beauty and "sense of place".
> *Supporting services* are necessary for the sustained provision of all the previously described services. These include primary productivity, soil development, nutrient cycling and mineralization of organic matter (source of soil fertility for plant growth), water cycling and the production of the oxygen.

Not all ecosystem services are provided at the same geographical scale (Díaz & Cáceres, 2002): "sense of place" is a local service that benefits people in or around the ecosystem in question. Carbon sequestration has global benefits through reducing the concentration of CO_2 in the atmosphere. Not everyone benefits from the services provided by a given ecosystem. Harvesting trees in a forest for timber certainly represents a provisioning service for foresters and urban dwellers in need of houses or furniture. However, it does not benefit those who use the forest for other benefits such as medicinal plants and game (also provisioning services) or attach a particular importance to its trees (a cultural service). Because different people benefit from different sets of ecosystem services at different geographical scales, it is important to assess land-use change impacts on ecosystem services through a multi-stakeholder perspective. This will enable us to identify those sectors of society that have been more (or less) impacted by the modifications the soy boom has induced in ecosystem structure and function in the Reconquista area.

In the *Cuña boscosa* plains and Paraná floodplain, reduced access to forest products (timber, fuel wood, medicines and honey) is the main environmental impact of recent land-use change in the Reconquista area. However these ecosystems still provide numerous ecosystem services to both local inhabitants and society in general. In the *Domo Oriental* however, the environmental impacts of agricultural intensification and homogenization are more varied. They include decreased food security for the rural poor (security being understood as both objective food availability and subjective assessment of one's ability to obtain it); health issues related to pesticide use (air spraying around houses and water pollution); soil degradation and loss; biodiversity loss (in-field through specialization and out-field through pesticide use) and landscape homogenization.

Using the ecosystem service framework, we made a qualitative assessment of the impacts of the dominant agro-industrial model and the alternative agro-ecological model on both the most and least vulnerable social groups in the case-study region. Peasants and decapitalized farmers as well as rural workers and urban poor are the most vulnerable sectors of society (losers in both the agro-industrial and agro-ecological models, but more so in the former). Successful commercial farmers, following either the agro-industrial or the agro-ecological model, as well as the more well off urban population are the least vulnerable. Although it provides important financial benefits to some segments of society, the agro-industrial model generates many negative impacts, not only in the *Domo oriental* where it expanded, but also on in the adjacent Paraná floodplain and the *Cuña boscosa* plains (Table 9.1). These negative impacts affect all segments of society through the loss of important ecosystem services. The agro-ecological model, on the contrary, brings many environmental benefits, especially to the more vulnerable segments of society (Table 9.1).

Conclusions and policy implications

Land-use change policies should strive to generate win-win configurations, where economic viability for some does not come at an environmental cost for others. In spite of being associated with poor peasants, recent developments (e.g., *Naturaleza Viva*) in the Reconquista area have shown that the alternative agro-ecological model can be economically viable, generating income and employment as well as environmental benefits.

Options for win-win land-use configurations are perhaps more feasible in the Paraná floodplain and the *Cuña boscosa* plains which have been less impacted by agricultural intensification and landscape homogenization. However, it is also possible to envisage win-win configurations in the *Domo Oriental* by increasing the share of the alternative agro-ecological model in that area. Many people in the Reconquista area have maintained an intimate knowledge of its ecosystems. This makes the development of win-win configurations based on this alternative model still possible, given adequate institutional support.

Institutional support is what is most lacking for the expansion of the alternative model in the region and in Argentina in general. Fostering the development of new,

locally embedded institutions (such as the ADR) could help, but only if they can operate in a broader institutional context that can accept an integrated vision of land-based resources (environmental, productive and social) and that shares equity goals. Developing such a context requires an active participation from national, provincial and local levels of government.

Table 9.1: Qualitative evaluation of the effects of existing land-use model on ecosystem service provision to more and less vulnerable stakeholders. The signs "-", "+", and "0" indicate negative, positive and neutral (respectively) impact of the dominant and alternative agricultural models on ecosystem services (lines) for a given stakeholder type (columns). G and L indicate the global and local (respectively) scale at which ecosystem services are provided. A question mark indicates insufficient knowledge while a blank indicates that the ecosystem service is not relevant for a particular stakeholder type.

Ecosystem Service	Scale	Dominant model			Alternative model		
		Local stakeholders		Society in general	Local stakeholders		Society in general
		More vulnerable	Less vulnerable		More vulnerable	Less vulnerable	
Provisioning services							
Food	G	-	+	+	+	-	-
Genetic resources	G	-	-	-	+	+	+
Non-Timber Forest Products	L	-	-		+	+	
Fiber	G	0	+	+	0	-	-
Timber	G	-	0	0	+	0	0
Fuel	G	-	0	0	+	0	0
Drinking water	G	-	-	-	+	+	+
Regulation services							
Polinization	G	-	-	-	+	+	+
Resistance to invasive & exotic species	L	?	?		?	?	
Micro- & meso-climate regulation	L	-	-		+	+	
Carbon sequestration	G			-			+
Pest control	L	-	-				
Water purification	L	-	-		+	+	
Erosion control	L	-	-		+	+	
Natural hazard mitigation	L	-	-		+	+	
Cultural services							
Food & health security	L	-	0		+	0	
"Sense of place"	L	-	-		+	+	
Recreation (including aesthetic beauty)	G	-	-	-	+	+	+
Knowledge & inspiration	G	-	-	-	+	+	+
Supporting services							
Primary productivity	G	-	-	-			
Habitat provision for wildlife & game	G	-	-	-	+	+	+
Nutrient cycling	G	-	-	-	+	+	+
Soil development and conservation	G	-	-	-	+	+	+
Oxygen production	G			-			+
Water cycle regulation and maintenance	G	-	-	-	+	+	+
General Trend		**-**	**-**	**-**	**+**	**+**	**+**

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10.

Agroecosystem functioning and management in semi-arid Northeastern Brazil

Ignacio H. Salcedo and Rômulo S.C. Menezes

This chapter presents major findings on agroecosystem dynamics and management in semi-arid NE Brazil obtained during the IAI Project CRN001. We begin describing the main environmental and socioeconomic characteristics of the region followed by a simple conceptual model that describes a typical agroecosystem and its principal processes of biogeochemical cycling of nutrients and water. The model is used as a framework to discuss research results from CRN001 and to identify gaps for future research activities.

Description of the region

The semi-arid region in NE Brazil extends for almost one million km^2 and has a rural population of 26 million people, which makes it one of the most densely populated semi-arid regions in the world. Native vegetation is primarily a deciduous thorn bush dry forest, locally known as caatinga. Intense exploitation during the last 2-3 centuries, which included deforestation, permanent and shifting cultivation, extensive cattle production and extraction of ecosystem products such as fire wood, strongly modified the original environment. The rate of deforestation has been estimated at 2.7% per yr and >80% of the vegetation is secondary growth, half of which is kept in pioneer stage by shifting cultivation and wood extraction. Despite the pressure, biodiversity is relatively high, with 1102 plant species identified (Gamarra-Rojas and Sampaio, 2002). Most of the population lives below the poverty line and relies on subsistence agriculture, thereby increasing the pressure on natural resources.

One of the main characteristics of the region is a high variability of landscapes and environments. The dry forest vegetation is distributed in 17 large landscape units, subdivided into 105 geo-environmental units (Rodal and Sampaio, 2002). Highly variable relief contributes to the large number of geo-environmental units. Average altitude varies between 400 and 500 m but can reach 1000 m. Approximately 37% of the area has slopes between 4-12% and 20% of the area >12% (SUDENE, 1985). Irregular rainfall patterns also contribute to environmental variability. In absolute values, rainfall is adequate for agriculture; in 29% of the region it varies between 750-1000 mm, in 54% between 500-750 mm and in 17% between 250-500 mm. However, on average, 20% of the annual rainfall will occur in a single day, and 60% in a single month (Sampaio, 1995), making annual values of limited use. Potential evapotranspiration is relatively stable between 1500-2000 mm yr^{-1} throughout the region (Sampaio, 1995; SUDENE, 1985). Average annual temperature is between 23 and 27°C with an average monthly variability of 5°C and diurnal variability of 5-10°C.

In spite of the high environmental variability, land use change in semi-arid NE Brazil has been driven primarily by socio-economic factors. During the last century, increasing population progressively fragmented the land tenure into small farms (75% < 10 ha), which are now incapable of supporting the families during droughts. The complex interactions of land degradation, declining yields, droughts that can last 3-4 years and other socioeconomic factors, eventually determine land abandonment in some areas. Land use in most farms includes both agriculture and livestock production, but the area currently occupied by agriculture (corn, beans, cassava and cotton) is estimated at 10% of the region while extensive cattle raising (mostly bovine but goats and sheep are also important) occupies the remaining area. Forage species in pastures are predominantly native plants that grow spontaneously after the selective logging or deforestation of caatinga.

Agroecosystem functioning and management

To facilitate a discussion of agroecosystem functioning, we developed a conceptual model of carbon, nutrient and water cycling in a typical farm of the semi-arid NE region, which includes crops, animals and a corral (Figure 10.1). The model indicates the main processes responsible for biogeochemical cycling in these systems which were divided into three types: 1) processes that promote resource **inputs** to the system; 2) **outputs** from the system; and 3) **internal cycling** of resources.

Soils are usually poor in fertility, particularly regarding N and P levels. A typical soil analysis is: extractable P 4 mg kg^{-1}; total P 150 mg kg^{-1}; extractable K 90 mg kg^{-1}; (Ca+Mg) 4 cmol$_c$ kg^{-1}; Al <0.2 cmol kg^{-1}; pH 6.2; total organic C 10 g kg^{-1}; total N 0.9 g kg^{-1}; 16% clay, 19% silt, and 65% sand. Soils developed over crystalline rock are usually shallower (0 to 60 cm) than those in valleys or on sedimentary parent material (>1 m deep).

Resource outputs from the agroecosystems

Two main types of outflows can be defined, a) those that do not generate income and therefore should be avoided (slash-burning, soil erosion, water losses), and, b) those that generate income for the farmer (farm products). Management practices should aim at eliminating the losses and maintaining the cash-generating outflows at sustainable levels.

Ecosystem losses are initiated with the slash-burn of native vegetation. Kauffman et al (1993) reported C, N and P losses from various aboveground biomass parts and recoveries by ash deposition in three experimental fires of varying intensity. The driest slash lost 96, 96 and 56% of the pre-burn C, N and P. When the slash drying period was reduced from 94 to 80 days, N volatilization decreased to 20% and P losses were completely avoided. Thus, if slash-burn cannot be avoided, there is the option of reducing nutrient losses by burning the slash with a higher moisture content to reduce the burn temperature.
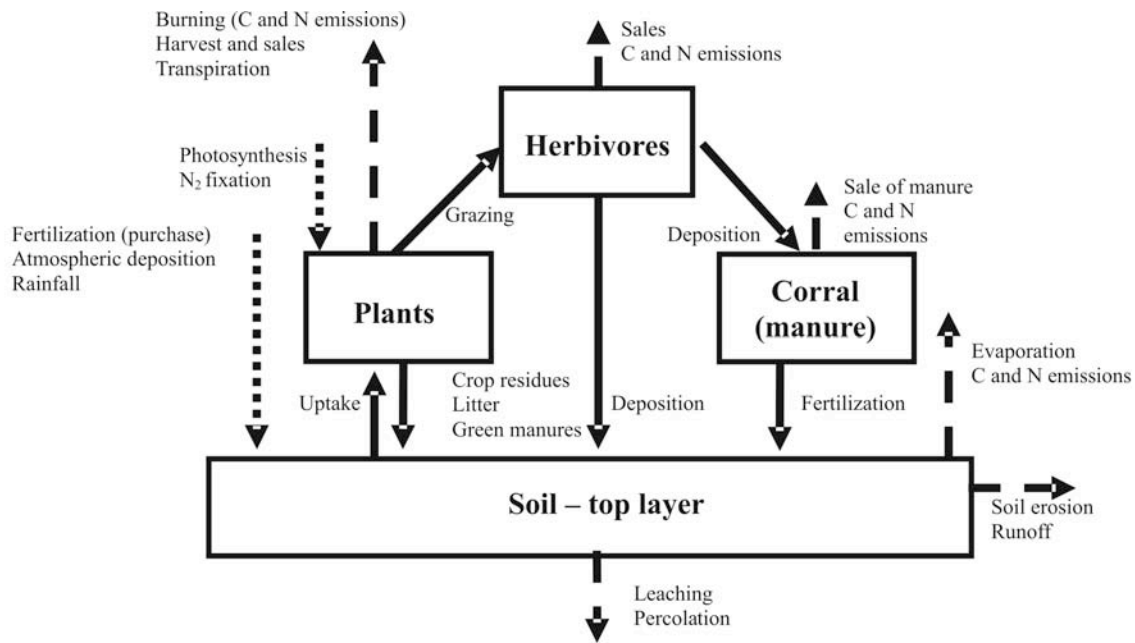
Figure 10.1. Main compartments and fluxes of carbon, nutrient and water within a typical agroecosystem in semi-arid NE Brazil. Dashed and dotted arrows represent resource outputs and inputs from the system, respectively, while solid arrows represents internal receource cycling.

Organic C losses from soils arise from mineralization processes and, in areas of undulating relief, from erosion processes. Mineralization rates depend on soil moisture conditions. Soil CO_2 fluxes under caatinga vegetation closely follow rainfall distribution (Souza, 2000) as does in-situ N mineralization under maize (Menezes and Salcedo, 2007). Greenhouse experiments, incubations and field measurements, indicated that approximately 6% of total SOM is mineralized during the 3 to 5-month growing season. Therefore, maintaining inputs of organic residues to the soil is essential for long term sustainability. SOM mineralization also affects the relative proportion of organic and inorganic P forms. The average organic to inorganic P ratio (Po/Pi) changed from 1.5 under preserved caatinga to 0.82 in cultivated degraded areas (Fraga and Salcedo, 2004). In soils of predominantly P-Fe chemistry this is not a desirable situation, since inorganic P is strongly retained by the clay-size particles of the soil, making it unavailable to the plants.

Nutrient depletion in soils also arises from plant absorption. Net nutrient outflows from these agroecosystems are mainly related to production of grains, milk and meat. Average withdrawals by grains and straw amounted to 16, 1 and 18 kg ha^{-1} yr^{-1} of N, P and K, respectively (Menezes et al., 2002a), similar to losses reported in Africa of 22, 2.5 and 15 kg ha^{-1} yr^{-1} of N, P and K by Sanchez (2002). Where land use is more intense, or where crops are more demanding, nutrient removals can be higher. A study of 50 *Opuntia* (a cactus used for forage in NE Brazil) fields showed nutrient removals of 300, 107 and 1454 kg ha^{-1} of N, P and K, respectively, in an accumulated dry matter yield of 45 t ha^{-1}

obtained three years after planting (Menezes et al., 2005). Nitrogen removal in these sites represented 7% of total soil N (close to 2% per yr) in the 0-20 cm soil layer; P removal amounted to 3% of total P and 35% of extractable P (Mehlich-1) and K removal was twice the amount of exchangeable K. While N exports can eventually be replaced by N fixation, P and K removals can only be counterbalanced by the addition of organic or inorganic sources of these nutrients. The problem of nutrient depletion in farm soils is aggravated when farmers decide to sell the manure accumulated in the corrals to earn extra cash. These losses amounted, on average for each farm, to 100, 40, and 150 kg yr^{-1} of N, P, and K, respectively (Menezes et al., 2002a). Therefore, manure sales should be discouraged by raising awareness among farmers about the importance of returning the nutrients not only to food crops, but also to *Opuntia* fields and pastures.

Erosion also plays an important role in soil degradation. A single 1-mm layer of surface soil eroded from a slope of one hectare redistributes 13 t of sediments and, on average, 130, 13 and 1 kg of C, N and P respectively. Farmers would hardly notice such loss. Losses of 35 mm and 250 mm soil layers were recently measured at sites in semi-arid and sub-humid areas respectively, using ^{137}Cs data (Fraga and Salcedo, 2004; Santos, 2004). In addition to C and nutrient losses associated with the sediment, SOM mineralization of newly exposed soil surfaces was enhanced, reinforcing the negative effect of the erosion process (Fraga and Salcedo, 2004). Such large losses of SOM-rich top soil seem incompatible with systems that rely solely in bush fallow to recover the fertility of abandoned areas. The combination of very small N stocks, low P status soils and water limitations certainly impose severe restrictions on the recovery of abandoned farmlands or can even prevent full recovery (Salcedo et al., 1997).

Strong soil erosion also indicates water losses through runoff. A significant portion of the runoff is redistributed within the landscape to the valleys, where the most valuable cropping areas are located (Galvão et al., 2005). Once in the valley, part of the water infiltrates in the soil and part of it goes downstream through ephemeral rivers and is lost from the watershed, often carrying the clay fraction in suspension. Since all cropping areas in the valleys have been deforested, all the water that infiltrates to the subsoil is lost from the rooting system, because the main crops (maize and beans) are not able to explore deeper soils layers efficiently.

Management practices to reduce soil and water losses must be encouraged. Our activities have demonstrated that well known techniques such as the establishment of contour rows of vegetation (*Opuntia, Gliricidia, Leucaena* and others) in areas with steep slopes are capable of reducing soil and water losses significantly. Surprisingly, soil erosion remains almost unrecognized as a severe problem in the region. A few recent initiatives have started to generate case studies that may help to spread the recognition of this issue.

Resource inputs to the agroecosystems

As seen above, resource outputs from the agroecosystems may be very high. Usually, these losses should be compensated to maintain ecosystem productivity but, considering that most farmers live at subsistence level, resource inputs to the agroecosystems are basically dependent on natural processes. Rainfall is the only water input and is a scarce

and unreliable resource, very irregularly distributed within and between years. Irrigation is not possible in most of the region because there is no water or because groundwater is often saline and unsuitable for irrigation.

Most farmers do not purchase fertilizers, so nutrient inputs depend on atmospheric deposition and biological N fixation. There have been no studies quantifying atmospheric deposition in semi-arid NE Brazil, but data from other regions in the world show inputs around 5-10 kg ha^{-1} year^{-1} of N. Biological N fixation may contribute more significant additions. Even though caatinga vegetation has a large number of leguminous species, there has been very little research on their ability to fix atmospheric N_2 in association with *Rhizobium*. With funds from CRN001 we have begun to evaluate the N fixation potential of 32 native legumes, using ^{15}N natural abundance. Preliminary results from field studies have shown that fixed N ranges from 30 to 70% of total plant N. Twenty of these species, under greenhouse conditions with three soils, showed nodulation with *Rhizobium* (Freitas, 2008).

In a few areas of the region, farmers are able to buy manure and usually this has great impact on soil fertility, particularly P. However, only farmers growing cash crops, mostly vegetables, with access urban markets, and in areas with higher precipitation can afford manure. Since most farmers have access only to the manure produced within the farms, we discuss manure management as a way of increasing resource use efficiency below.

Increasing resource use efficiency

Water and nutrient use efficiency

Since water is the major limiting resource for plant growth in semi-arid regions, CRN001 invested efforts to both improve the understanding of the water cycle and to develop management alternatives for more efficient use of available water in agroecosystems. In a three-year study, we found that during the 4-month growing seasons, an alley cropping system of *Gliricidia sepium* and maize was able to utilize over 100 mm more water from the soil profile (0-100 cm), particularly from depths > 60 cm, than a maize plot without trees. This greater water uptake was accompanied by an average 85% increase in total biomass production during the three years of the study. In addition, trees contributed to the stabilization of biomass productivity, since they were able to produce biomass quickly after the first rains and kept producing for at least two additional months after the rainy season ended (Marin et al., 2007).
Another example of increased water use efficiency was observed in a study that quantified biomass production in 50 fields of *Opuntia* across the semi-arid region. Increasing planting density and soil P availability led to a 10-fold increase in biomass production per mm of rainfall (Menezes et al. 2005).
Tree effects on soil fertility were reported by Menezes and Salcedo (1999) and Menezes et al. (2002b) who found "fertility islands" under the canopy of three tree species, in comparison to the surrounding soil under pasture. Using tracer techniques with ^{13}C and ^{15}N, Tiessen et al. (2003) showed that nutrients accumulated in the top soil under tree canopies were deposited on the soil surface by litterfall and probably originated from

deeper layers. Additional evidence of the positive effects of trees on soils fertility were obtained at basin scale. While total N content in soils (0-20 cm) under cultivation (crops or pastures) averaged 1.8 t ha^{-1}, it increased to 2.5 t ha^{-1} under *Mimosa caesalpinifolia*, 2.8 t ha^{-1} under bush-fallow and 4.5 t ha^{-1} under native montane forest (Galvão et al. 2005; Santos 2004). The trend was similar under drier climate conditions, since soils (0-15 cm) under caatinga vegetation contained 2.3 t N ha^{-1} while in cultivated areas was only 1.3 t N ha^{-1} (Fraga and Salcedo 2004).

Organic fertilizer management

Farmers in NE Brazil usually incorporate animal manure to the soil, independent of type and quality of the manure. In years of low rainfall, poor quality, low-N manure mixed with straw induces N immobilization and reduces crop yields. CRN001 activities have raised awareness among farmers associated with the project about organic fertilizer quality and its relation to decomposition and synchronization between crop demand and soil nutrient availability (Perez et al., 2006; Perez and Menezes, 2004; Tiessen et al., 2003). We suggested fertilization practices, such as the combination of animal manure with *Crotalaria juncea*, a legume cover-crop, which increased crop productivity by up to 300% (Silva and Menezes, 2007). The recommendation to use *Gliricidia sepium* leaves as green manure has increased maize productivity by up to 250%. However, the biomass of legumes is usually highly valued as forage, and some farmers do not accept incorporating it to the soil. For this reason, we are currently evaluating the quality of native species considered to be weeds that could be used as green manure by subsistence farmers. Management recommendations will depend on the levels of nitrogen, secondary metabolic compounds and lignin of different species (Vanlawe et al., 2005). Species of high quality (high N and low lignin and secondary compounds) are recommended for direct incorporation in the soil while low quality materials are recommended either to be composted before incorporation or to be used as mulch.

Another important aspect of nutrient dynamics currently being investigated is the residual effect of different types of organic fertilizers. Manure applications by farmers are usually done every year, independent of previous additions, leading to build-up of soil nutrients, particularly P, within cropping fields. Information regarding the residual effect of fertilizers will allow farmers to increase the fertilized areas through the rotation of areas to be fertilized every year.

Final remarks

Given the restrictions to achieve high primary and secondary productivities in the region, land use systems should aim at production of biomass with higher aggregated value, instead of grains and meat. Among the options to be explored, are the hundreds of native, endemic species that may supply pharmaceutical products and oils, for example. The development of sustainable agroecosystem management practices requires the adoption of participatory methodologies. A key for success is to include and consider all stakeholders; special emphasis must be given to revalue and integrate traditional

knowledge within new research methods and decision-making processes that facilitate the generation and adoption of those practices.

Simulation models are an important tool to advance the study of agro-ecosystem function and to support the development of management alternatives. Initial steps were taken in cooperation between partners from Argentina and Brazil (Peinetti et al., 2008) and we expect cooperation to be expanded in the future. Cooperation is also needed with climatologists in order to understand how extreme rainfall variability affects the potential for sustainability of the various land use systems. The coefficient of variation of annual rainfall precipitation has been used in other arid and semi-arid regions in the world to optimize regional distribution of land use systems (Ellis, 1994; Caughley et al., 1987).

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11.
Land use and cover in riparian areas of the Andean Amazon: Consequences for people and ecosystems

Michael E. McClain, Rosa E. Cossio, Daniel Gann, and Thomas J. Saunders

People living in rural and urban areas of the Andean Amazon region are heavily dependent on goods and services provided by the ecosystems surrounding them, and future sustainable development in the region is constrained by environmental factors. Among the region's abundance of unique ecosystems, riparian zones bordering rivers and streams stand out as offering the most diverse array of services. Riparian zones contain the region's most fertile soils. Their vegetation yields food, fiber, and medicinal herbs, while at the same time providing habitat for important game animals, stabilizing river margins against erosion, and protecting rivers from land-based sources of pollution. Riparian zones also provide access to navigable rivers that serve as important transport routes in this largely roadless region.

The IAI Collaborative Research Network on "Andean Amazon River Analysis and Monitoring" examined the relationships between climate, terrain, land use, human demographics and river systems. Riparian zones were a focal area, and results emerging from this research have important implications for future management strategies.

Regional context

The Andean Amazon region contains some of the world's most rapidly changing landscapes stretching along the eastern flank of the Andean Cordillera from southern Colombia to central Bolivia. The region covers more than 600,000 km^2 and hosts an enormous diversity of ecosystems ranging from lowland dense moist forest (500-700 m asl) to montane forest (700-3700 m asl) and high elevation grasslands (>3700 m asl). Forests originally covered more than 85% of the region, but today nearly 40% has been converted to human uses producing a mosaic of montane vegetation, shrubland and agriculture (Eva et al. 1998). Most deforestation and land conversion is attributed to colonists migrating into the region from highland and coastal regions. While this is largely true, and colonization has taken over formerly indigenous lands, indigenous peoples themselves are in many places turning to more intensive land uses and are assimilating themselves and their communities into local and regional markets (Santos-Granero and Barclay 1998).

Rivers are a defining feature of this region and have played a central role in the formation of its biodiversity and the development of its burgeoning human populations (Salo et al. 1986, McClain et al. 2001). Andean Amazon rivers contain diverse assemblages of fish and other aquatic organisms, and important lowland fish species migrate annually into Andean rivers to spawn (Barthem and Goulding 1997, Montreuil et al. 2001, Diaz-Sarmiento and Alvarez-León 2004). These fish are critical to the

nutritional welfare of people in the region and can account for 50% or more of the animal protein consumed in some areas (McClain et al. 2001, Ayllon 2002). Most people in the region take their drinking water from streams and rivers and consume it untreated, thus relying on the natural processes of purification within rivers. With increasing pollution from towns and livestock, however, natural purification processes are no longer sufficient in many areas, and water-related illnesses are spreading (Puentes 2004, Blanco 2005, McClain et al. 2001).

The value of riparian zones

Riparian zones and river flood plains throughout the Amazon have held special value for humans since prehistoric times (Meggars 1984, Whitehead 1994). Chief among these values is the fertility of riparian soils, which is generally higher than that of surrounding upland soils. More fertile soils support more protein-rich crops valued by the people of the region. Agriculture remains the principal activity of most people in the Amazon.

Households in the Pachitea communities of Laguna-Raya and Santa María (Figure 11.1) cultivate distinctly different crops in upland and riparian areas (Cossio 2003, McClain and Cossio 2003). The main crops cultivated in uplands are high-carbohydrate manioc and plantain, as well as some citrus and coffee. Riparian crops, by comparison, are predominantly higher protein corn, peanuts, and beans. Corn is generally cultivated on elevated terraces with medium-fertility soils, while peanuts and beans are cultivated on the most fertile soils along the present banks of the rivers. This pattern of cultivation has been observed in other Andean Amazon communities as well. Mestizo households of the Tamshiyacu community in northeastern Peru cultivate corn, beans, and rice on seasonally exposed floodplain soils while cultivating manioc on adjacent uplands (Hiraoka 1986). Similar practices have been reported for communities along the Ucayali River and upper Solimões of Brazil (Padoch and de Jong 1992, Shorr 2000).

The bulk of biogeochemical research in riparian zones has featured their role in regulating fluxes of water, sediment, and solutes (especially nitrogen) between terrestrial and aquatic systems (Naiman et al. 2005). In addition to serving important ecosystem functions, this regulatory effect protects aquatic systems from land-based sources of pollution like runoff sediments and agrochemicals from upland agricultural areas (Lowrance et al. 1997). The regulatory and buffering characteristics of riparian zones have also been documented in the lowland Amazon, as has the effect of deforestation in reducing their buffering capacity (McClain et al. 1994, Williams et al. 1997, Thomas et al. 2004).

Similar riparian functions are expected in lower valleys of the Andean Amazon, where broad, well-developed riparian zones border river systems. The functioning of riparian zones in higher Andean valleys is less certain, because higher valleys are narrow and steep, their riparian zones narrow, and contact time for rapidly flowing runoff waters is reduced. Frequent landslides further complicate riparian processes in steep valleys, and soils are generally shallow and poorly developed. Despite these differences, research in small streams of the Pachitea Basin confirmed that riparian zones in Andean mountain systems perform similar ecosystem functions (Ramos et al. 2003, Saunders et al. 2006) to those in lowlands.
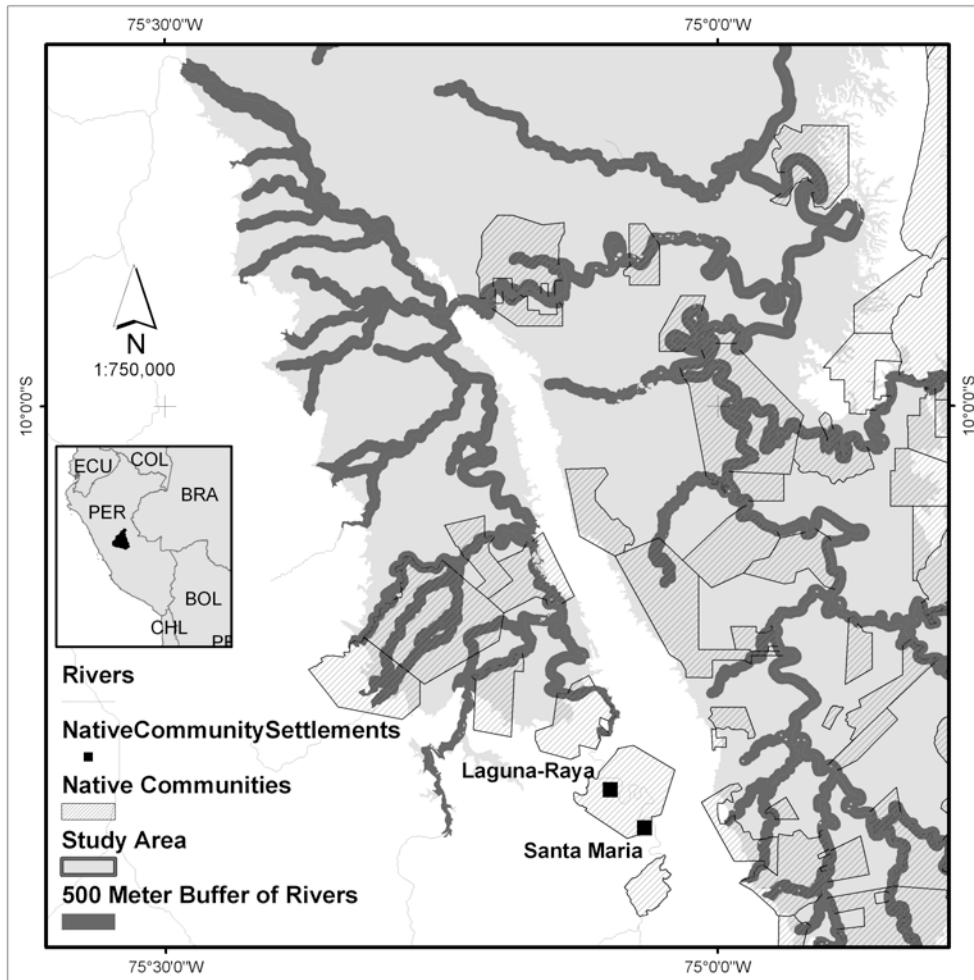
Figure 11.1. Map of the Pachitea study area. Land cover classification was carried out in the area shaded gray. Polygons delimit indigenous communities. 500 m buffers around rivers are dark gray. The communities of Laguna-Raya and Santa Maria are labeled.

Analysis of nutrient and organic matter chemistry along runoff pathways in a headwater stream at 2400 m asl in the Pachitea basin demonstrated strong terrestrial controls on N, P, and dissolved organic carbon. During the wet season, the narrow riparian zone buffered significant increases in nitrate (NO_3^-) and dissolved organic nitrogen (DON) originating in ground waters flowing from adjacent forested uplands (Figure 11.2)(Saunders et al. 2006). The riparian zone held a 'reserve buffering capacity' that significantly reduced increases in NO_3^- and DON concentrations in the river. Retention of soluble reactive phosphorus, ammonium (NH_4^+), and dissolved organic phosphorus and carbon was not significant. Although absolute values of different parameters varied according to season (wet or dry), patterns of groundwater nitrogen retention were consistent throughout the year. Another important finding was that storm runoff pathways such as overland flow and throughfall carried higher concentrations of inorganic nitrogen to streams, thereby negating the retention capabilities of riparian soils (Ramos et al. 2003, Saunders et al. 2006). Nutrient monitoring data from larger rivers in

the basin showed a similar response to storm runoff events (McClain et al. unpublished data).
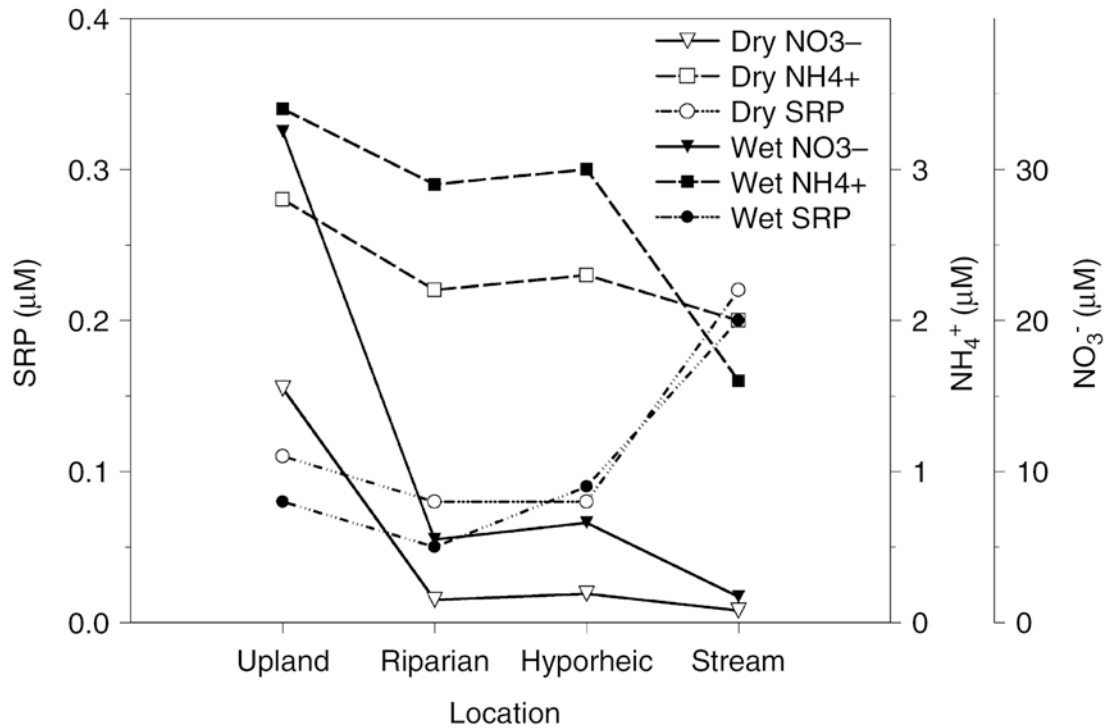
Figure 11.2. Spatio-temporal variation in median nutrient concentrations from upland, riparian, hyporheic (beneath the stream), and stream samples from a headwater stream valley in the Pachitea Basin, Peru (From Saunders et al. 2006)

While riparian zones are recognized for their ecological value in present-day ecosystems, they also influence biodiversity and ecological processes at spatial and temporal scales far beyond present-day riparian boundaries. Over much longer timescales, riparian environments in the tropics have served as refuge for plant species during climatic shifts, often dividing plant populations and stimulating species diversification due to unique local conditions (Aide and Rivera 1998). As a result of their role in the protection and formation of biodiversity, riparian zones are recognized as important components of long-term ecosystem and biodiversity conservation plans.

Though spatially confined when compared to their lowland counterparts, riparian zones in tropical montane forests are situated in environments particularly sensitive to global climate change. Still et al. (1999) and Foster (2001; and references within) discuss the potential for a decrease in cloud formation at lower elevations, effectively shifting the base elevation of cloud formation hundreds of meters higher. As cloud forests harbor large numbers of endemic species (Leo 1995) and are dependent on cloudwater inputs to maintain populations of moisture sensitive plant species such as bryophytes and other epiphytes (Coxson 1991), a shift in cloud contact time could have drastic effects on the stability of the ecosystem (Foster 2001). The role of riparian zones as habitat refugia during climate change is of particular relevance in the tropical Andes given its high levels

biodiversity, mountainous environment, and high density of low stream-order riparian corridors.
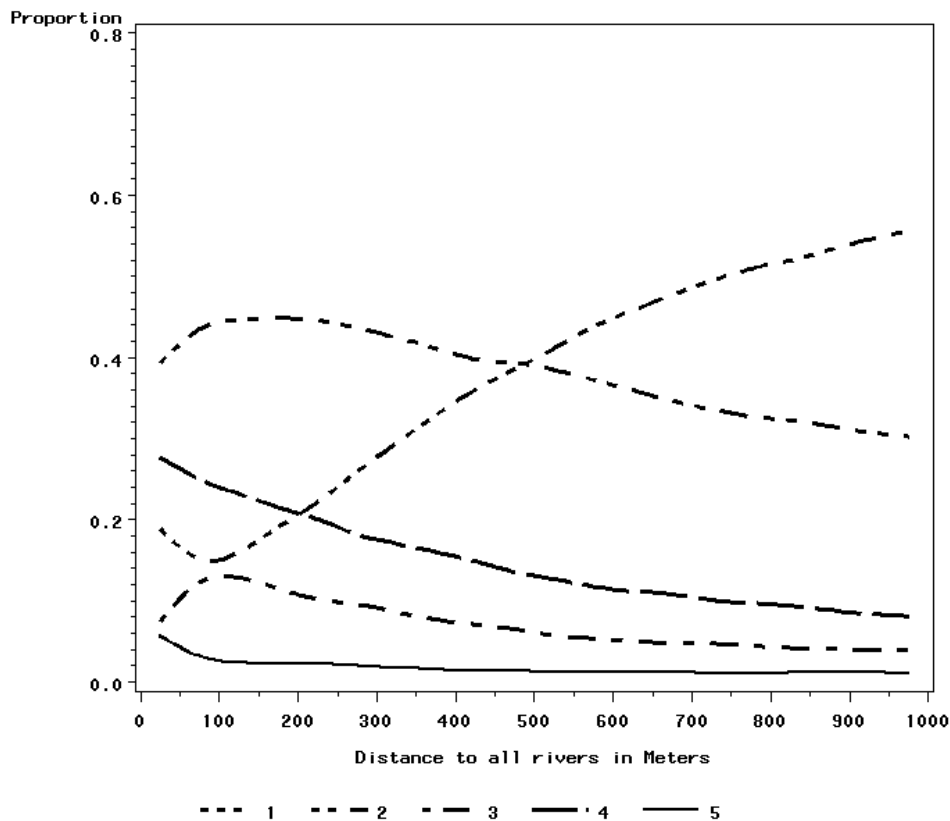

Land Cover in Riparian Zones

The rapid rates of land conversion in the Andean Amazon, coupled with the central role of water in the lives and livelihoods of the region's people, makes riparian zones vulnerable to some of the most intense change. As part of the CRN project, land cover and use was investigated in a 5500 km^2 area of the Pachitea Basin (lightly shaded area in Figure 11.1). The analysis excluded the steep mountainous portions of the basin, which are largely forested and uninhabited, and focused on the broad valley bottoms where the majority of the population lives. The analysis distinguished between three sub-basins of the Pachitea to evaluate historical influences on land use, between areas controlled by colonists and indigenous people to investigate socio-cultural controls, and between areas adjacent to and distant from rivers (Gann 2003). Minor differences were found as a result of both sub-basin and cultural control. The Palcazu sub-basin, which was the first to be colonized, had the lowest percentage of closed-canopy forest. Because indigenous people are largely acculturated into the local markets of the basin, there was no difference in the percentage of closed-canopy forest between indigenous- and colonist-controlled lands, or between the proportions of other land covers (Gann and McClain, unpublished data).

The proportions of different land covers on land within 500 m of rivers were significantly different from basin averages (Table 11.1). The proportion of closed-canopy forest within 500 m of rivers (26%) was less than half that in the study basin (57%). Conversely, areas proximal to rivers had twice the percentages of pasture and agriculture. Percent cover of early and late succession forest was also higher within 500 m of rivers. Trends in proportions of land cover with increasing distance from rivers are clearer in Figure 11.3.The highest proportions of agriculture and grassland occur within 100 m of rivers. The proportion of agriculture, in particular, is greatest along rivers. The lowest proportion of closed-canopy forest occurs within 100 m of rivers, and closed-canopy forest proportions mirror those of early succession forest. Late succession forest makes up the greatest proportion of land cover adjacent to rivers, but gradually decreases with distance away from rivers.

Table 11.1. Areas (hectares) and percentages of land cover in the entire 5500 km^2 area of the Pachitea study area and within 500 m of the nearest river.

Land Cover	Study Area		Within 500 m of River	
	Area (Ha)	Percent	Area (Ha)	Percent
Closed Canopy Forest	316879	57.5	306	25.9
Late Succession Forest	157875	28.7	505	42.6
Early Succession Forest	22827	4.1	112	9.5
Grassland	46751	8.5	234	19.7
Agriculture	6574	1.2	28	2.3
TOTAL	550909	100.0	1185	100.0

Figure 11.3. Proportion of different land cover classes with distance from rivers. 1 is closed-canopy forest, 2 is late succession forest, 3 is early succession forest, 4 is grassland, and 5 is agriculture.

Use and Management of Riparian Zones

Effective management of riparian zones is a challenge that requires a fine balance between use and conservation. On the one hand riparian zones contain the region's most fertile soils, capable of growing nutritionally and commercially important crops with little or no fertilizer. This encourages maximal conversion of riparian forest to cultivation. On the other hand riparian zones are critical to the protection of surface water quality and the habitat and basic energy sources on which aquatic species depend. This encourages maximal protection of riparian forest. The proper response to these conflicting motivations is careful management to reap the agricultural benefits of riparian zones without compromising their protective capacities. To successfully implement necessary management actions, people of the region must value riparian zones and also comply with practices specified in management plans.

To investigate the status of current riparian area use in the Pachitea Basin, the perceptions of people toward them, and compliance with existing rules, 79 households

were surveyed in two communities (Cossio 2003, McClain and Cossio 2003). Laguna-Raya is an Amuesha native community that owns its land communally, while Santa María is a predominantly colonist community where each family holds a title for their own land. Households in both communities cultivated agricultural plots in riparian areas (1 ha/household in Laguna-Raya and 2 ha/household in Santa María). Both communities also left a portion of riparian zones for protection. According to Peruvian forest law, a 50 m wide forest buffer must be maintained between surface waters and agricultural activities. In Santa María this requirement is specified in the individual land titles held by households, while in Laguna-Raya the 50 m rule is specified by the community's own General Assembly. According to survey results, the mean widths of riparian forest buffers in Laguna-Raya and Santa María are 22 and 27 m, respectively (McClain and Cossio 2003). Protective forest buffers were reported to lie along 99% of river margins in Laguna-Raya, and along 82% of river margins in Santa María. The higher compliance in Laguna-Raya was attributed to its stronger communal structure.

A majority of households in both communities (100% at Laguna-Raya and 82% at Santa María) recognized the special environmental value of riparian zones. Moreover, the primary value expressed in both communities was for soil protection. Overall the findings of this study are encouraging, especially given that little or no governmental effort is exerted to enforce riparian management rules.

Strategies of the Future

The findings of the project and similar research programs throughout the Amazon suggest that effective protection and management of riparian forests are essential to sustainable development in the Andean Amazon region. Functionally intact riparian ecosystems, because of their integrated effects across terrestrial and aquatic systems, provide a wealth of goods and services that cannot be matched by any other single ecosystem type. Moreover, their combined services are irreplaceable, and it is inconceivable that the countries of the region could afford engineered systems to substitute for even a small proportion of riparian services (e.g. river bank stabilization and pollution prevention).

Continued research will provide greater understanding of the functional aspects of riparian forests, but knowledge gained to-date is sufficient for action. Our findings, although limited in geographic scope, suggest that riparian zones of the Andean Amazon region remain largely intact and functional. The condition of riparian zones in the Amazon is far better than that in North America and Europe, where more than 80% of natural riparian zones have disappeared over the past 200 years (Naiman et al 1993). Additionally, both indigenous and colonist inhabitants of the Andean Amazon recognize the value of riparian forests and are willing to preserve them. This combination of knowledge, favorable status, and individual willingness presents a remarkable opportunity to implement resource management actions that reinforce current good practices and strengthen institutional and individual capacities to preserve these critical services.

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12.
Amazonian cattle ranching: Towards a new social-environmental agreement

Jean-François Tourrand, Hermes Morales Grosskopf, and Charles H. Wood

The main objectives of the IAI project on cattle ranching in the Amazon were (i) to explain the reasons for the development of a cattle ranching in Amazonia that is detrimental to natural forest ecosystems and then (ii) interpret these results in local, regional, national and international public policies. The different environmental, social, direct and indirect externalities in the expansion of cattle ranching, and the need to integrate forest and pastoral activities, demanded a multidisciplinary approach, including social, technical, cultural, political, economic and agro-environmental disciplines. The aim was on the one hand to harmonize methods for analyzing the impact of cattle ranching on the environment, and on the other hand to cooperatively define, model and begin validating methods how to use rural space in a manner that is less harmful to the environment while considering the needs and desires of the local populations

Related to the colonization process of a space by a society, social externalities of cattle ranching have been present since ancient times: the Peuls who left the Arabian peninsula thousands of years ago to occupy the Saharan and sub-Saharan Africa, the Mongols who transformed the Asian-Hindu-European space into their Empire of Steppes several centuries ago, or more recently the European pioneers conquering North and South American territories.

When drawing up the project, we considered the different environmental and social externalities derived from the expansion of cattle ranching during the history of humanity.

Questioning the place of cattle ranching in societies

Strong negative environmental externalities of intensive livestock production systems are evident in industrialized regions, particularly Holland, Brittany, and the region of the Great Lakes, but the participation of ruminants in global warming must also be considered. It looks as if industrialized society no longer accepts that its agriculture is contaminating its environment, water, air and landscapes. This raises questions about productivity and impacts generated and about the place of animals in a society. These questions are also at the heart of cattle production in Amazonia and is being considered by the administrators and local authorities in the region. A critical task therefore is to reduce the negative effects of cattle production in a comparative frame without knowing which of the livestock systems, Amazonian or industrialized, has the greater environmental impact.

The Pampas - an environmentally correct cattle ranching model for Amazonia?

The Pampas region of Argentina, Uruguay and Brazil is associated with the image of cattle ranching on grass, vast spaces, in harmony with its environmental, cultural and economic requirements. Soon after the arrival of the Europeans on the American continent, the *Pampas* region became, thanks to its exceptional bio-climatic environment, a great zone for bovine and ovine ranching. Until the 19th century the principal production was leather, but since the 20th century, particularly since its wars, the region has been producing meat for export. With the advent of refrigerated transport, the *Pampas* have developed into one of the first river basins for the production and export of bovine meat on a worldwide scale. Amazonian cattle ranching is largely in the hands of *gauchos* or their descendants from the Pampas. In what way can the experience of the *Pampas* be useful in orienting the present dynamics of cattle ranching in Amazonia, particularly through public policies?

The expansion of cattle ranching in Amazonia

With barely five million bovines, Amazonia was virtually unknown as a cattle ranching region at the beginning of the sixties, but in less than half a century it has developed into one of the most important beef production regions world-wide. Officially, the region now boasts over fifty million heads, but the figure is probably nearly double that based on the number of Brazilian cattle vaccinated against foot and mouth disease. For nearly a decade, Amazonian meat, and, recently milk, has been marketed mainly outside the region. Amazonian meat is now dispatched to urban and foreign markets, which, until now, have been supplied by traditionally pastoral regions. This reorganization of the Brazilian market has turned the country into the largest exporter of beef. Export from the Amazon has incrased from 250-400 thousand metric tons a decade ago to over two million metric tons now.

Complex social, economic, cultural, bio-climatic and political factors account for this development of cattle ranching in Amazonia. There are similarities between Amazonia and the *Pampas*. Both are suitable for grass production and cattle raising. Secondly, given that the rights of Amerindians are scarcely taken in account, land is available plentifully and a pioneering society culturally predisposed towards cattle ranching is occupying a new life and production space.

The environmental impact: from natural forests to grasslands

Unlike the *Pampas* where the development of cattle ranching has been largely respectful of the region's natural ecosystems, the development of cattle ranching in Amazonia depends on destroying natural forest ecosystems. It is estimated that today grass occupies approximately 80% of the deforested area and 15-20% of the Amazon has been deforested with little variations between countries. On average approximately 1% of Amazonia has been deforested annually over the past 20 years and 80% of this newly deforested land is transformed into grass.

Considering Amazonia in the context of climate change, biodiversity loss and respect of the environment, the impact of the expansion of cattle ranching on deforestation has become an important public issue. Different protagonists are involved, including civilians and public administrators on a local, regional, national and international scale.

Differentiated impact between Amerindian societies and settlers

A focus on deforestation conceals the main social impact on Amerindian societies, namely the advance of the pioneering fronts which can be seen as a continuation of the colonization of the South American continent by the white culture. Colonization began on the Atlantic coast and progressed inland, integrating the societies encountered, dominating or destroying them. European breeds of cattle were abandoned in favour of the zebu when settlers reached the inter-tropical space.

On the other hand, cattle ranching has been a key element providing livelihoods in Amazonia to thousands of settlers who had fled from poverty in their native regions in search of of land in Amazonia to survive and continue the reproduction of their family group. Since the beginning of the 90's and in the absence of an economically profitable alternative, a large number of smalltime settlers has turned to cattle ranching, with the result that the dialogue which had been dominated by preconceptions about large landholders has now become less ideological, more pragmatic and somewhat less scathing.

The issue of the forest as a fertility reserve for settlers

Contrary to the ecologists view of the different services and functions of the forest the settler sees in the forest little but harvestable trees and a vegetal mass that can be slashed and burned in order to fertilize the ground it occupies. As soon as the 2-3 exploitable trees per hectare have been felled, all forest parcels are cut and burned and the land is cultivated and sown with grass for cattle ranching. It is important, therefore, to invest in the education of these settlers and increase their awareness with the view of achieving a better realization for the forest's other functions.

The situation is different in the Amerindian societies whose exploitation of forest products is much more diversified, while also taking account its different social, religious and nourishing functions. In traditional shifting cultivation, there are long fallow periods, which enable parcels to recover fertility. However, both in Brazil and in the Andean countries, the gradual integration of the Amerindian communities in the market economy is leading to an increasingly intense exploitation of forest resources, frequently involving forest companies and surpassing sometimes the threshold of sustainable management. Toni et al (2005) in the Brazilian State of Acre and Ludovino (2002), then Barbosa (2005) on the island of Marajó in Eastern Amazonia have shown a gradual adapting to exploitation systems by Mestizo societies that are similar to those of the settlers, particularly as regards cattle ranching. Traditional methods based on rotations between annual cultures and long fallow are increasingly discarded.

Throughout the 1970s and 80s slash and burn was widely practiced in the piedmont (high forest, at 500-1500m), and more recently at lower altitudes (300-500 m altitude) of all the Andean countries of Amazonia in order to cultivate cocaine. In these cases, the pioneering fronts destroying the natural ecosystems appears to have been confined to zones of cocaine production and so far it has not spread to Brazilian Amazonia.

Considering the present tendency in the advance of pioneering fronts that the different governments in the area are unable to control, and the adoption of the settlers' landuse system by traditional societies, it is urgent to reinforce the protection of some designated forest spaces, if only as a testimony for future generations. We have the example of Mata Atlantica which has been reduced to 6-7% of its initial surface today.

Settlers' lack of valuation of forest capital

For settlers, forest is simply a fertility reserve and consequently the valuation of forest capital is very low. Many studies show that, on the pioneering front, the value of forest is reduced to the trees used for the construction of infrastructure, houses, sheds and fences. Or else trees are sold at ridiculously low prices to forest companies (in the range of US$30-50 for a tree that will produce 5-6 m^3 of wood and be sold for US$500-1000/$m^3$ on the domestic or international market). These logging practices only take into consideration the currently exploitable trees. When the wood is sold one single time, a forest parcel produces an income ranging from US$50 to US$100/ha. The young trees, which will not be exploitable for several years to come, are transformed into smoke and ashes. Nevertheless, it is possible to think that maintaining the forested parcel, and taking advantage of potential wood growth, could generate a regular business every 4-5 years. In addition, as is the case in some forest concessions, it is possible to improve the wood yield of a parcel by adopting a maintenance management and thinning so as to improve existing potential and develop interest in secondary species.

Wood incomes, therefore, that can be extracted from a forest every 10-12 years, are similar to the incomes achieved by using the same surface area as grassland. In the light of this, research and development is needed, and ecologists, foresters and agraronomists should work together on the integration of agricultural and forest activities. In addition, some studies show the possibility of adding value to wood resources by establishing wood factories in small communities to produce wood for the manufacture of different furniture and hand made devices on a local scale. In addition to wood, a forest parcel contains various other products. These products are potentially exploitable but until now have been very much neglected, even in the Amerindian and Caboclo communities. Several studies completed in the past twenty years have shown good market value for some of these edible, pharmacological or other products. They emphasize local scale organization as the main difficulty for a better return on these activities. Some products are particularly interesting, because of the demand of the international market, for instance for the Pará (or Brazil) nut. Other products are interesting for a regional market, such as the açai in Eastern Amazonia or natural and traditional medicines in all regions. It is important to invest in the development of these

products, and not only in the scope of economic investigation, so that these local sectors may become operative and produce the awaited results.

Payment for environmental services is a new tool to help local actors in Amazonia preserve the environmental functions of the forest. Several initiatives have been taken. Some, triggered by international groups, have an economic and speculative character in relation to the fixation of carbon. They may have implications on large-scale production, but do not affect small family farms, such as those of the Amerindians, the Caboclo or the smalltime settlers. Big international companies sell carbon credits, but small farms are unable to meet the requirements of environmental service certification.

The necessity to preserve the environmental functions of forest on a local scale

Selecting the forest parcel that is going to be cut, burnt and then cultivated is a land occupant's decision. The choice is governed by the need to establish a perennial culture that requires a fertile soil. As a rule, a permanent home is constructed near a water point. Following that and regardless of topography, the first parcels to be cultivated and turned into grassland are the ones nearest to the house. The farms commonly are divided in two sectors: an agricultural sector located around the house with access to water, and a forested sector forest which is gradually reduced in size, further away from the house towards the edge of the property. The deforestation of water margins and slopes has lead to an accumulation of sand in rivers and a disturbance of hydraulic regimes. In all cases, the impact can be seen on the farms and in the communities. There is a lack of water for human and animal consumption in the dry season and an increase of floods during the rainy season.

The provision of areas of permanent protection - APP - (springs, shores and steep slopes) is not yet the norm, although it offers the opportunity to increase the forest surface area of a property and thus approach the legal deforestation limit that is now often a required condition to be granted new loans, at least in Brazil. The designation of APP is consequently a field of investigation for ecology, forestry and agronomy.

The environmental function of forest is not simply limited to the control of hydraulic regimes. Ecologists have shown the harmful effects of forest fragmentation in the pioneering fronts. It is essential to study this matter on the scale of the different communities with the view of planning the best possible action and future organization of APPs. We have the example of two localities parallel to the Trans-Amazon route in Brazilian Eastern Amazonia, where some fifty farms of approximately a hundred hectares each have maintained forested land on between 30 and 50% of their respective surface areas. In its entirety, this constitutes a forest reserve of approximately 2000ha. This collective local scale action will need management and possibly a counterpart of public policy on a more regional and river basin scale.

Green hell to green desert

As a great consumer of space, cattle ranching encourages the dispersal of families. In Amazonia, a herd of 200-250 cows is just enough for a family to survive with an annual

net income of approximately U$10-12,000 and a labour force of 2-3 people. However, in the present conditions, this herd with its heifers, calves and bulls requires a grass surface area of 400 to 500 hectares. The space organization of such a system corresponds to a dispersed habitat with a nuclear family every 400-500m. This complicates matters for the life of a community, especially as regards healthcare and education. In other cases, where the habitat is more concentrated, most families have to travel, sometimes several kilometers, to get to their work places.

In the case of forestry operations, similar incomes with the same labour force can be achieved with surface areas of a few dozen hectares, in part cultivated with perennial cultures (cacao, coffee, tea, banana). This land development method leads to a more concentrated habitat with the constitution of villages and consolidated communities. For that reason, in a system devoted to pastoral activities, numerous families, encouraged by the great flexibility in the size of the working force and working time on cattle ranches, prefer to emigrate towards the nearest city. Hired labor lives on the farm, to accomplish day-to-day management tasks. This encourages land concentration. Indeed, several factors encourage some families to sell their land, mainly to obtain urban incomes, to invest in city ventures, weakening the families' agrarian culture. On the other hand, this leads other families to invest in land and cattle, buying the land sold by the displaced families. In parallel, the transfer of the decision making centre in relation to the place of the pastoral activity would appear to affect farmers' interest for the environment, in as much as the farm is seen more and more as a simple means of income and, in some cases, a place to relax during vacations or weekends.

Conclusion: public policies serving territorial development

Some key elements essential for the framework of a territorial development policy derived from the above are:

- The development of cattle ranching was one of the main factors in the survival of numerous settlers in Amazonia due to its essential functions in the production of income and savings. It was also a key factor in the accumulation of land, both for the smalltime settlers emigrating to survive, such as the foresters who invested their savings on farms, or the businessmen of the bordering regions attracted by the profits generated by cattle ranching in Amazonia.
- The development of cattle ranching whether in family or commercial farms has damaged forest ecosystems in a similar manner. Neither family nor the commercial farms have taken interest in protecting the environmental functions of forest.
- During the first stage of the colonization process, the destructive expansion of the pioneering front is hardly controllable, no matter what means of protection are used. For that reason, it seems advisable to concentrate these means on the conservation of natural forest spaces, representative of the diversity of ecosystems.
- After the devastating phase of the colonization process, it is probably possible to initiate actions aimed at reconstructing rural landscapes in which forest and agricultural and pastoral activities all have their place. Several proposals have been made in

Amazonia, with good results that are worth confirming on a medium to long-term scale.

- The involvement of local actors is essential throughout the reconstruction process of rural landscapes. This means educating and informing local populations as soon as possible after the initial colonization process. The guidelines and instruction must be given in both the urban and rural communities, with a particular attention to young people.
- Whithout provision for funds that will help in the establishing of integrated pastoral-forestry systems, the Amazon will continue to be dominated by the pioneering use of the natural resource available.

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13.

Tropical forests, functional diversity and ecosystem services: Characterisation and perspectives in relation to global change

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The key role tropical moist forests play in the regulation of ecosystem processes and services at multiple scales, the characteristics of these forests and the services they provide will be affected by global change. We will here characterize the functional diversity of woody species in tropical forests, its potential relationship to the quality and quantity of ecosystem services, and how these characteristics and processes of the biosphere are impacted by the massive anthropogenic global change currently under way. The concepts and methods of plant functional ecology are undergoing rapid development. This chapter is derived from the objectives, principles and lines of work set out in the Collaborative Research Network (IAI-CRN II 2015, Functional Biodiversity Effects on Ecosystem Processes, Ecosystem Services and Sustainability in the Americas: an interdisciplinary approach, initiated during 2006 and led by Sandra Díaz).

What is plant functional diversity?

Biodiversity is still perceived by many people largely in terms of plant and animal species, and measured or estimated as numbers of species or species richness. In the last twenty years, however, scientists have placed increasing emphasis on the nature and importance of other facets of biodiversity: that biodiversity has structural and functional as well as compositional components that can be measured at multiple scales from the global to the local (Noss 1990). Thus compositional biodiversity can be evaluated and managed at levels from the genetic (for example, the alleles present in a population) to that of natural community types in landscapes or regions (for example, the climatically-determined vegetation types in a country). Functional diversity as conceived by the conservation biologist Noss includes genetic and ecological processes: from gene flow, the movement of alleles between species populations due to dispersal, to ecosystem processes such as the production of biomass or the hydrological cycle. A more recent definition of plant functional diversity was given by Díaz et al. (2006): the value, range, and abundance of functional traits in a given community or ecosystem. Plant functional diversity is linked to the fundamental principle of biology that the characteristics of organisms and the communities they constitute are closely linked to the ecological processes in which they participate. Fruit-eating bats differ in anatomy and behaviour from nectar-eating bats in direct relation to their feeding habits, where feeding can be seen as an ecological process, and its consequences – seed dispersal in the first case, and pollination in the second – as ecological functions or as ecosystem services to farmers (Ricketts 2004).

Plant species, the communities they constitute, the processes in which they are involved and thus the functions they perform, vary in important ways (as those illustrated for bat species) but for many people are probably not easy to perceive. The understanding of plant functional diversity at the levels the species and the community is critical to the understanding of the biosphere and the impacts of global change, because of the role of plants as primary producers – the route by which solar energy enters food chains. There is wide recognition that the classification of plant species according to their botanical taxonomy "has important limitations when it comes to answering important ecological questions at the scale of ecosystems, landscapes or biomes" (Cornelissen et al. 2003), because plant taxonomists do not classify plants using functional criteria. Because of convergent evolution, plant species that are completely unrelated phylogenetically can be functionally similar. This consensus has arisen only now after ecologists dedicated much effort during the 1990s to the search for a relationship between species diversity and ecosystem functioning, based on the influential hypothesis from the 1950s that communities should be more stable the more species they contain (Pimm 1984, Townsend et al. 2003)

Much of the theory and empirical information that constitute today´s field of plant functional diversity is not new – the concept of ecosystem function, for example, has been in textbooks since at least the 1960s, and scientists have been measuring components of ecosystem function, plant productivity for example, for much longer. But awareness of the vitally important relationship between taxonomic (compositional) diversity and the quantity, quality and sustainability of ecological functions, is relatively new among researchers and funding institutions.

The first component of the understanding of functional ecology of tropical moist forests is the characterisation and description of the functional diversity among forest tree species. The starting point for the characterisation of plant functional diversity is the identification of functional traits. These can be defined as measurable morphological, anatomical, architectural or physiological characteristics of plant species that affect the functional responses of the individual plant – e.g. the way in which it responds to environmental change – or its functional effects – the way in which the plant influences its biotic (e.g. competing neighbours) or abiotic (e.g. the plant´s effect on local microclimate or soil conditions and resources) environment (Díaz and Cabido 2001, Lavorel and Garnier 2002).

The sometimes large number of plant species in a community can normally be assigned to a smaller number of functional groups or Plant Functional Types (PFTs) on the basis of shared functional characteristics, although procedures for achieving this and the meaning of the resulting groupings are debated (e.g. Pillar and Sosinski 2003, Wright et al. 2006b). The number and type of PFTs found in a community depend on the objectives of the study. Since there tends to be a continuous variation of plant traits in most communities (Díaz et al. 2004, Lavorel et al. 2007), classification of species into categories (communities, PFTs) is always somewhat artificial. Plant species can be united in ecological groups according to shared characteristics such as growth rate, longevity or fecundity. These ecological groupings predated the current field of plant functional ecology, but they are first approximations of PFTs (see: Grime´s (1979) general framework, and reviews by Budowski, 1965; Gómez-Pompa and Vásquez-Yanes, 1981; Whitmore, 1990 and Finegan, 1996). Definition of discrete PFTs is a valuable practical

tool for management and conservation. The functional composition of a plant community can be described on the basis of the PFTs represented and the relative abundances of individuals belonging to each PFT. The PFT substitutes for the botanical species in the description of composition. The evaluation of the functional traits of plants in a community makes it possible to calculate functional diversity (FD) of that community (Díaz and Cabido 2001, Tilman 2001). In plant functional ecology, FD can be seen as the equivalent of the widely-used indices of ecological diversity calculated, in traditional community ecology, on the basis of the number of species in the community and the relative abundance of each (Magurran 1988).
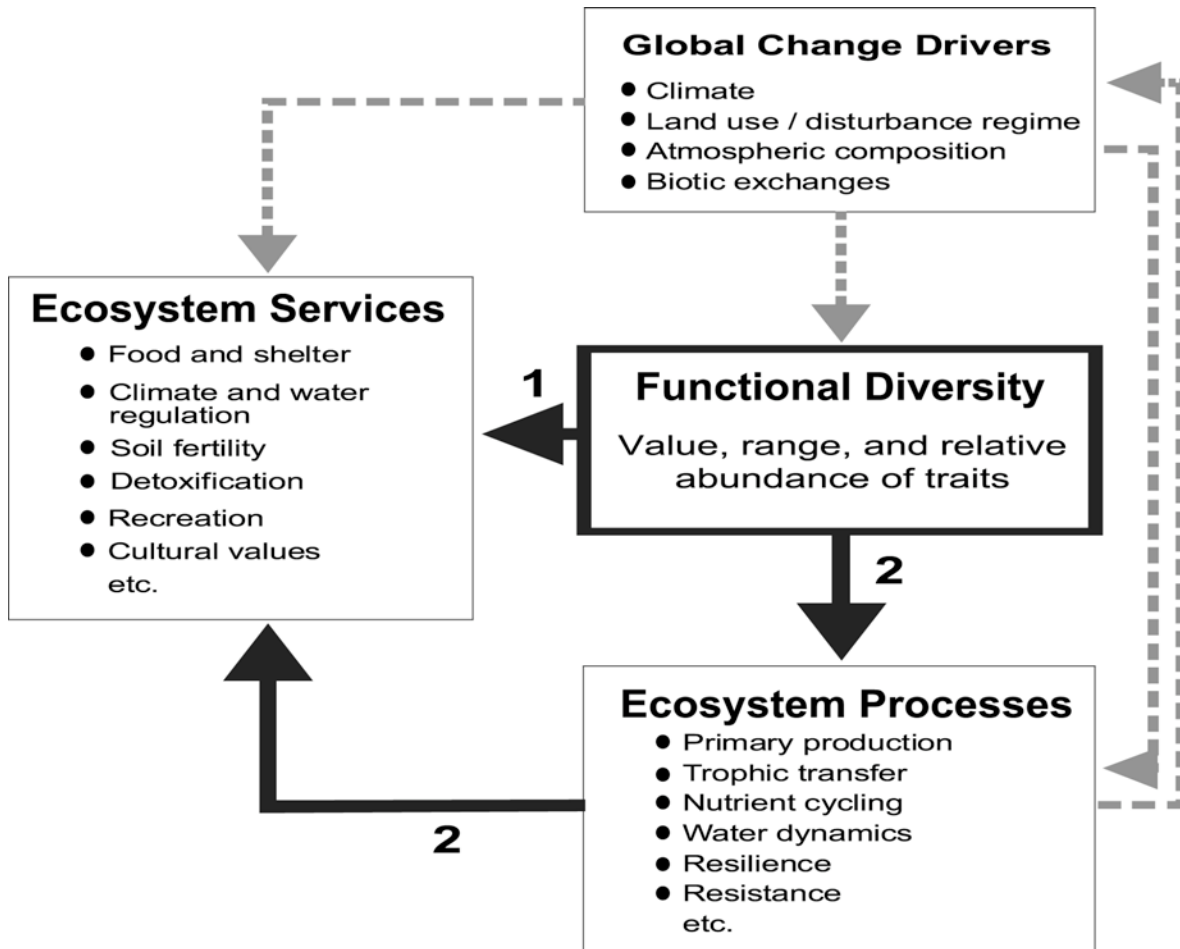
What are ecosystem processes and services?

Ecosystem processes such biomass production, energy flow and the cycling of nutrients and water (Townsend et al. 2003), because of their importance to human wellbeing are increasingly described as ecosystem services. Ecosystem services can best be defined as the benefits provided by ecosystems that contribute to making human life both possible and worth living (Millenium Ecosystem Assessment 2005), or that measurably contribute to human welfare (Boyd and Banzhaf 2006). Functional diversity has the potential to determine the type, magnitude and rate of ecosystem processes, and therefore the type and the magnitude of the ecosystem services provided.

How are plant functional diversity and ecosystem services linked?

An increasing number of researchers acknowledge the importance of moving from an approach based solely on species numbers towards an approach based on better understanding of how functional biodiversity (FB) influences ecosystem functioning (Díaz and Cabido 2001, Naeem and Wright 2003, Hooper et al. 2005).   Biodiversity plays a role in the provision of major ecosystem services (Daily 1997, Balvanera et al. 2005, Millenium Ecosystem Assessment 2005, Díaz et al. 2006) either directly (Figure 13.1, path 1) or indirectly (Figure 13.1, path 2). An example of a direct effect is the aesthetic value and sense of place related to a certain configuration of species in a familiar landscape: the particular arrangement of canopy structure, leaf shapes, and scents that are recognized as familiar and pleasant. An example of indirect effects is the maintenance of soil fertility: nitrogen-rich, deciduous leaves decompose easily and lead to high soil nutrient availability; an evergreen canopy, on the other hand, is associated with lower decomposability and lower temperature at the soil level, leading to lower soil fertility. Ecosystem services are perceived and valued differently by different social actors (e.g. Cohen 1996, Krupnik and Jolly 2002). For example, in the case of a dry subtropical forest, national and regional governments may value most its capacity to sequester carbon and regulate runoff into water reservoirs; subsistence farmers will value most its capacity to provide traditional medicines, fuel, and grazing for their livestock; ecotourists will value its capacity to sustain wildlife and large-statured individual of tree species; and urban dwellers will value its capacity to provide timber. In addition to local

stakeholder interests, FB may also affect ecosystems services that are perceived at a regional or global level such as N cycling and C sequestration (Chapin et al. 2004).

Figure 13.1. Functional diversity (FB) is both a response variable modified by, and a factor modifying ecosystem processes and global change drivers. FB affects ecosystem services directly (path 1) and also indirectly through its regulation of ecosystem processes that in turn affect ecosystem services (path 2) (modified from Díaz et al. 2006).

How will global change affect plant functional diversity and ecosystem processes ?

Among all global change drivers, land use change will likely have the greatest effect on biodiversity and ecosystem processes and services in the next decades, particularly in the developing world (Sala et al. 2000, Lambin et al. 2003, Duraiappah et al. 2005). The direct effects of land use practices (e.g. irrigation, burning) on ecosystem processes are relatively well understood. There is much less empirical evidence, however, on the possible indirect effects . Although the impact of diversity on ecosystem processes has been widely recognized, most of the research effort has focused on the effects of a reduction in species richness (Millenium Ecosystem Assessment 2005, Díaz et al., 2006).

The ecosystem consequences of changes in species composition and their relative abundances have remained less understood.

One of the main ways in which land use change can alter ecosystem function is by causing shifts in FB. These shifts mutually interact with climate. Climate acts to "filter" out certain functional traits and allows species possessing other traits to establish. An expected consequence is that narrower ranges of functional traits exist under more severe than under milder climatic conditions (Díaz et al. 1999, Schmid et al. 2002). On the other hand, dominant functional traits influence community and ecosystem responses to variations in climate and disturbance regime (Chapin et al. 1993, Laurance et al. 2004). Local FB and climate variability and change may also interact in complex ways producing important and often unexpected shifts in ecosystem functioning (Lavorel and Garnier 2002, Hooper et al. 2005).

When these shifts go beyond certain thresholds, non-linear, irreversible changes in ecosystem processes can occur, with often dramatic consequences for ecosystem services (Peters et al. 2004).

Solutions to environmental problems caused by human impacts on FB require working with real ecosystems under different land use regimes, and assessments of the human and ecological dimensions of changes in biodiversity and ecosystem functioning. In view of the accelerated land use changes triggered by the contrasting interests of different stakeholders, there is a need to understand the social and biological consequences of biodiversity change (Watson and Berghal 2003, Duraiappah et al. 2005). Alterations of FB lead to differential benefits and vulnerabilities for different stakeholders, both locally and remotely. This is an important emerging issue about which there is very little conceptual or empirical work.

The case of tropical moist forest

How much do we know about plant functional diversity in tropical moist forests?
The distributions of major vegetation types in relation to macroclimate, as set out for example in the Holdridge life-zone system (Holdridge 1982), represent a functional response of vegetation: temperature, precipitation and potential evapotransiration are major factors in the determination of characteristics of the vegetation such as dominant life form (forest, scrub, grassland), biomass and physiognomy. Particular combinations of macroclimatic factors produce the same vegetation types wherever they are found on the planet and independently of the phylogenetic origins of local botanical species. Irrespective of the underlying processes, the Mediterranean vegetation of California, Chile, Australia, South Africa and the Mediterranean basin is frequently cited as an example of macroclimatic determination of similar vegetation structure and function in floras that are only distantly related to each other phylogenetically. In the same way, however, the tropical moist forests of eastern Amazonia and the Pacific slope of Mesoamerica, or Indonesia and Papua New Guinea, converge in their structure and physiognomy even though they share few botanical species (Holdridge 1982, Whitmore 1984). We therefore expect tropical moist forests to show patterns of functional response similar to those demonstrated for better-studied biomes. It is useful to examine these patterns within a simple framework of three factors: the broad-scale influence of

macroclimate, smaller-scale variation with soil and topography within macroclimatic categories, and natural disturbance.

Plant ecologists have dedicated much effort to documenting tropical moist forest variation in botanical composition in relation to soil and topography (see reviews by Whitmore 1984 and Finegan et al. 2001b). It is likely that these changes in forest botanical composition in relation to soil and topography are paralleled by vegetation functional responses. Vitousek and Sanford (1986) reviewed understanding of these responses two decades ago: tropical moist forests on relatively fertile soils produce more leaf litter, for example, with higher nutrient contents and faster decomposition rates, than those on very infertile soils such as the Oxisols of some areas of the Amazon basin. At a much finer scale, Herrera and Finegan (1997) showed how two tropical tree species with contrasting leaf functional traits were distributed across a site in relation to local-scale variation in topography and soil conditions, thus advancing towards the degree of understanding of plant functional responses of well-known temperate tree genera such as the oaks (Cavender-Bares et al. 2004).

Natural disturbance is a major factor in the generation and maintenance of biodiversity (Pickett and Carpenter 1995) and the study of its occurrence and effects, in combination with the growing influence of humans, is a major line of research in tropical forest ecology. Disturbances in tropical forests vary in frequency, intensity, spatial pattern and area affected. It is now widely accepted that large-scale natural disturbance is frequent and that the influence of humans is pervasive (Burslem and Whitmore 1999, Chazdon 2003). Disturbance of tropical forest and functional ecology are linked through disturbance effects on microclimate. Functional groups among tropical moist forest tree species may be distinguished in relation to light requirements which are correlated to factors of growth rate, longevity, time to reproductive maturity, adult size, wood density and leaf characteristics such as nutrient content (e.g. Thomas and Bazzaz 1999, Wright et al. 2006a). These traits are closely linked to functional responses to natural and human disturbance, and are crucial to our understanding of global change in tropical forests (Bunker et al. 2005, Vieira et al. 2005). If, as in other biomes, conservative and acquisitive tendencies of tree species (Díaz et al. 2003) permit funcional groupings of tropical moist forests, a small number of functional groups can be defined between attributes of strongly light-demanding, fast growing, short-lived and effectively-dispersed (among other things) species, and slow-growing, shade-tolerant (at least as juveniles), long-lived and more dispersal-limited species. The former group, of course, is predicted to predominate under conditions of frequent, intense natural or human disturbance.

A major contribution to understanding tropical moist forest ecosystem functioning and ecosystem services will come from easily measurable traits that are indicators of physiological function. For example, specific leaf area and seed mass are good surrogates for harder to measure relative growth rate and persistence in the soil seed bank, respectively (see Hodgson et al. 1999, Lavorel and Garnier 2002 for more examples). The height of mature individuals of 28 Malaysian forest tree species was shown to be positively correlated with the light-saturated photosynthetic rates of their saplings (Thomas and Bazzaz, 1999). Among recent proposals of PFTs for tropical forest tree species, an analysis by Poorter et al. (2006) assigned 54 species from a Bolivian seasonal moist tropical forest to four functional groups on the basis of 22 easily measured architectural traits. As part of our IAI/CRNII project, Salgado et al. (in prep.) have

assigned 308 botanical species from an aseasonal Costa Rican moist forest site to five groups on the basis of stem diameter growth rates and the height range occupied by the crowns of adult trees (Figure 13.2). , both of which can be taken as surrogates for harder-to-measure traits such as photosynthetic rates (as mentioned above) and, completing the link between functional traits and ecosystem processes and services, the cycling and sequestration of carbon (Vieira et al. 2005).
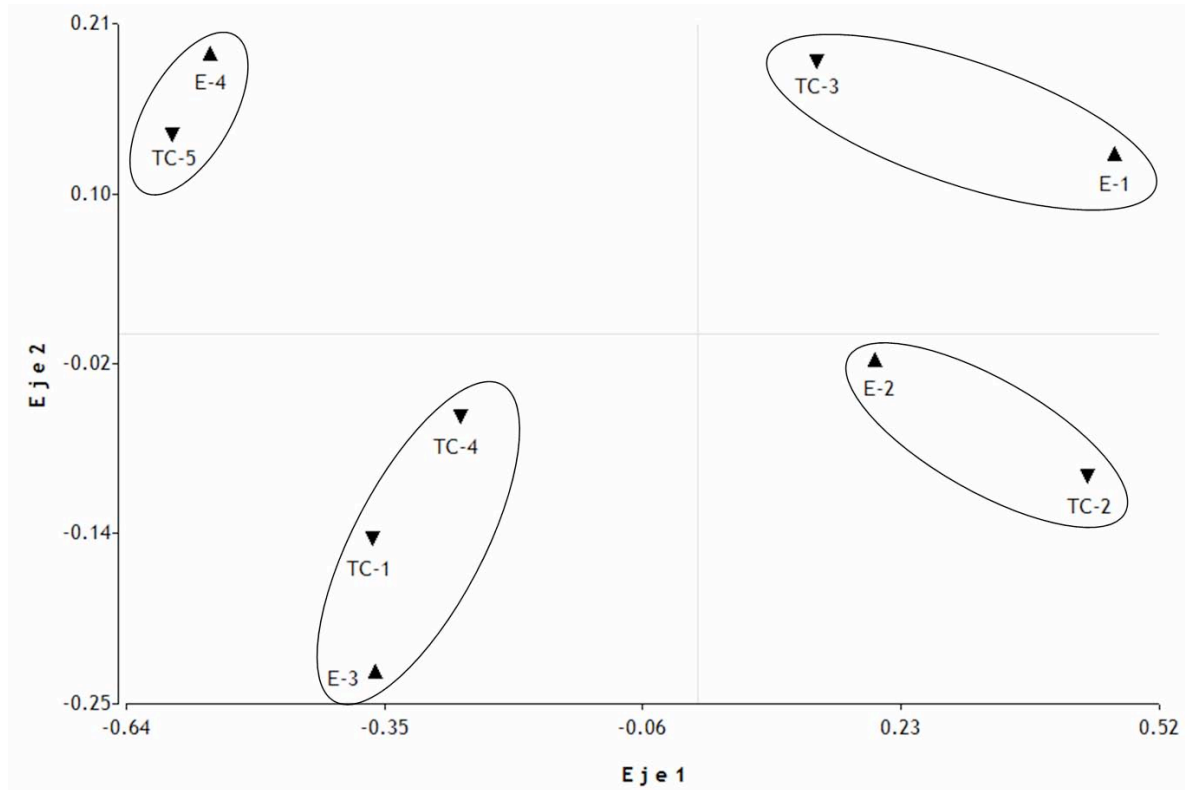
Figure 13.2. An example of a functional grouping in tropical moist forest tree species (Salgado et al. in prep.). The graph shows results of a correspondence analysis between stem diameter growth rates (five groups of botanical species, TC-1 – TC-5) delimited using cluster analysis of long-term measurements from permanent sample plots) and the size of adult trees (four groups according to the observed height ranges occupied by crowns of adults, E-1 – E-4), for a total of 308 species at a site in northeastern Costa Rica.

The results suggest functional groups: under- and middle-storey species with slow to moderate diameter growth rates (positive values on axis 1), and canopy and emergent species with fast or very fast growth, although individuals belonging to the latter height-range groups are also associated with very slow growth (negative values on axis 1). The next step in this work is to determine the impact of human disturbance on functional composition and diversity using these easily measured traits, and thus improve the understanding of ecosystem functional change. Such understanding of tropical forest

response to human disturbance on the basis of a small number of functional groups offers logistical advantages in comparison with working with hundreds of botanical species.

Predictions regarding human impacts on plant functional diversity in tropical forests

We focus on change on land under primary forest with no recent drastic disturbance, and on secondary forest, reestablished through natural secondary succession following agriculture. Human activity is universally expected to reduce the species and genetic diversity of natural communities and populations. "Biotic homogenisation" - the replacement of native taxonomic and functional diversity with largely non-native plants adapted to human-dominated ecosystems (Olden et al. 2004) is evident in the woody floras of human-dominated landscapes in seasonal lowland areas of mesoamerica (Finegan, personal observations). It is essential to be precise about the type, frequency and extent of the disturbances (Pickett and Carpenter 1995). In northeastern Costa Rica forest cover is ca. 50% and deforestation rates have been reduced to close to zero in the past ten years; pasture and cropland make up much of the matrix (Sesnie et al. 2008). In this landscape, taxonomic richness and diversity of tropical moist forest woody species is resistant (Pimm 1984) to disturbances such as low-intensity selective logging (Finegan et al. 2001a) or the edge effects caused by deforestation and pasture establishment (Schedlbauer et al. 2007). However, functional change occurs under disturbances such as commercial logging, and subsequent increases of the relative abundances of pioneer species (Finegan et al. 2001a, Forero and Finegan 2002, Chazdon et al. 2007). Functional change is most evident in the composition of secondary forests regenerating on abandoned agricultural land, in which fast and very fast-growing canopy and emergent tree species dominate (Fig. 13.2) rather than the mix of moderate to slow-growing species that dominate the original forest (Finegan 1996, Finegan et al 1999, Chazdon et al. 2007). Increased turnover rates - tree mortality and recruitment - accompany the these functional changes (Laurance et al. 2004), for example in logged and silviculturally treated primary forest (Finegan et al. 2001a).

Human-impacted tropical moist forests are predicted to exhibit more variable rates of emission (following disturbance) and fixation (due to regrowth) of carbon than in the original landscape. Functional change towards faster-growing species and more frequent disturbance may mean a net loss of carbon (but see Vieira et al. 2005), although there will be temporary increases in standing biomass during secondary succession. The carbon sequestration of landscapes will be a sum of patterns of change under individual disturbance regimes (e.g. selective logging versus edge effects versus forest clearing and regrowth).

The research by the Diversus Network is one of the first attempts to evaluate plant functional diversity (FB) in megadiverse tropical forests, its dynamics under the types of human impact established above, and the consequences of changes in FB in relation to key ecosystem processes, seeking to identify possible thresholds beyond which changes in FB lead to drastic and possibly irreversible changes in these processes. This work will be closely linked to a further component of the project, an evaluation of FB relationships to the value of ecosystem services from the forests studied, from both the technical point

of view – e.g. through evaluation of carbon storage and turnover - and the perceptions of the different stakeholders in the study area. Costa Rica has one of the planet´s few functioning Payment for Environmental Services (PES) programmes, and the work on ecosystem processes, ecosystem services and stakeholder perceptions will emphasise carbon fixation and storage, and aesthetic value especially in relation to the country´s burgeoning ecotourism industry. It is hoped that this work will lead to greater scientific understanding of the links between plant functional diversity and human wellbeing in the tropics, and greater awareness of these links and action to conserve them in society as a whole.

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14.
The tropical alpine treeline: A case study of a changing ecosystem boundary

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Why analyse ecosystem boundaries?

Each natural ecosystem occurs within an ecological hyperspace whose main axes are environmental factors related to air and soil temperatures, water and nutrient availability and interactions with other factors such as species or plant functional types. A boundary represents a sudden change in some of these determinants. Major structural and functional changes occur over relatively short distances across the boundary. This affords the opportunity to characterize the drivers that determine the occurrence of each of the bordering ecosystems and to show how changes in these determinants may lead to the replacement of one ecosystem by a quite different one.

Any natural boundary is a transition zone whose width may range from a few meters to a few kilometres. When the two ecosystems in contact have quite contrasting physiognomies, like the boundary between forests and non-forest formations, the precise nature of the ecotone may be more apparent and in many cases it may appear as a clear-cut border. However, even in these cases a narrow ecotone does exist where the forest and the open vegetation are competing for space.

Within the Cooperative Research Network of the IAI, CRN 2005 "From landscape to ecosystem: across-scales functioning in changing environments", we analyze several ecosystem boundaries throughout the Americas. Here, we discuss the boundary between montane forest and páramo (tropical alpine grasslands and heathlands) in the *Sierra Nevada de Mérida of the* Venezuelan Andes that occurs across an often complex ecotone which varies in altitude, width and pattern according to regional climate, land-use history and local, mainly topographic, conditions.

Natural boundaries?

One of the most challenging aspects of the study of ecosystem boundaries is their determination by a complex array of geomorphic, climatic and biotic interacting factors, from which it is difficult and often futile to choose a single, leading driver. In addition to biophysical determinants and limitations, human action has often shaped current boundaries. For instance, many forest areas have been modified by logging and burning, giving rise to isolated patches within a fragmented landscape. After deforested areas have been subjected to perennial or annual cropping, followed by periods of pasture and/or fallowing, the distinction between the former forest and other land units becomes obscure. Therefore, any analysis of the forest to non-forest transitional zones has to consider the history of land use over periods as long as a few centuries.

The upper slopes of the humid tropical Andes conserve extensive areas under natural or semi-natural conditions. Nevertheless, population pressure is steadily growing and leading to more intensive land use, which modifies or replaces the original ecosystems. As a consequence the biophysically-determined boundary has been altered, often in subtle ways, requiring a detailed landscape analysis to set apart natural from human-induced influences. Under what circumstances have ecosystem boundaries been more strongly shaped by human influence? And conversely, does the biophysical template influence the outcome of land use dynamics on the transitional zone? These are questions which add a new level of complexity to the study of ecosystem boundaries.

A steady state condition?

Any significant change in environmental conditions, when related to the occurrence of an ecosystem, could displace its boundaries if enough time passes for the adjustment of the ecosystem to the new conditions. Consequently, global temperatures, which show significant changes from long term means (Mann 2001), may be expected to change ecosystem functioning and boundaries. Global meta-analyses have documented significant range shifts toward the poles or toward higher altitudes for many organisms, and a large part of these changes may be attributed to increased global temperatures (Parmesan and Yohe 2003, Root et al. 2003).

Palynological and paleoecological studies on Quaternary vegetation and climates throughout the world have shown a consistent picture of continuous displacement of vegetation formations in accordance with climate oscillations. In the tropical Andes, from Venezuela to Ecuador, the montane forest belt and the páramo above, have reacted to these climatic changes by upward extension of the forest under warmer conditions and the downward advance of the páramo under colder conditions. More than 25 glacial-interglacial cycles were identified throughout the Quaternary (Van der Hammen 1991). The longest pollen sequences, a 350 m-deep core from the central highlands of Colombia, covers the Late Pliocene and the Pleistocene and shows the alternation of periods with striking differences of tree pollen representation, from less than 10% to more than 80%, suggesting continuous change between closed forest and open páramo vegetation (Hooghiemstra 1984). During one of the coldest periods, the Last Glacial Maximum (LGM 26.000-14.000 B.P.), the treeline was as low as 2000 m asl, about 1500 to 1800 m below its actual position, while the glaciers descended to about 3800 m, 1000 m below the actual snow line. During the warmest periods, the treeline was at about the same altitude as today (Van der Hammen & Cleef 1986).

After the LGM, during the Holocene, wide fluctuations in both temperature and rainfall occurred (Salgado-Labouriau 1986, Marchant et al. 2004). Data from one pollen core in the Ecuadorian Andes at 3870 m asl, suggest that the upper forest line has ranged between 3400 and 3700 m during the past 660 years, with a minimum altitude between ca. AD 1290 to 1315 (Wille et al. 2002). Likewise, in the Venezuelan Andes a continuous decadal-scale reconstruction of climate during the last 1500 yr, based on lake sediments (Polissar et al. 2006), points to a 300 to 500 m descend of the glaciers during the Little Ice Age (1180-1820 AD) which peaked four times: from 1180 to 1350, from 1450 to 1590, from 1640 to 1730 and from 1800 to 1820 yr AD. This lowering of the glacier

fronts is equivalent to a temperature depression of 2.6-4.3 ºC and rainfall of more than 200 mm above the present mean. After 1820 a persistent retreat of the glaciers, that seems to continue nowadays, is detectable in the sediment record.

All these data clearly indicate that the montane forest - páramo boundary has been continuously changing its position in the South American highlands, not only in synchrony with the glacial-interglacial cycles, but as a response to centennial and even decadal climatic variations. The current position of this boundary in the Andes results from the climate warming of the last two centuries with an upward displacement of the alpine ecotone of a few hundred meters. The actual boundary appears to be rather recent and continues to be moving upwards by some meters per century.

Alpine treelines at mid latitudes: lessons for the páramo – montane forest boundary

Several recent studies of Alpine treelines, defined as the elevation at which continuous forest gives way to alpine heaths and grasslands, have potential uses as indicators of climate change, since it is expected that with increasing temperature, trees will migrate upward into alpine regions. High elevation ecosystems should be among the first systems to register the impacts of global climate change, and as such these ecosystems represent a unique opportunity for understanding the complexity of biotic response to a mutable climatic setting. The position of the tree limit should be a sensitive indicator of such a response (Kullman 1998).

The Alpine treeline is a complex ecotone spanning a considerable elevation range. In mid-latitude mountains of both hemispheres it occurs at mean annual temperatures of 6 to 7º C and mean summer temperatures of 6.5º C (Korner and Paulsen 2004). Temperatures during the warm part of the year are the main control of forest line elevation in extra-tropical regions, while temperatures during the cold part of the year affect the dominant life form of trees (Jobbágy & Jackson 2000). This boundary is heavily influenced by topographic factors since mountainous rugged topography creates steep ecological gradients that modify climate. Yet, not only does the treeline follow climatic gradients determined by local relief, different plant communities may also respond to other factors topographic factors whose influence on climate is more subtle, such as slope and aspect.

The physical abiotic template appears as a co-determinant of ecosystem structure and functioning, emphasizing the importance of topography in understanding species response to climate. Patterns at the upper forest boundary include fine scale variation in climatic gradients where not only temperature but precipitation may play an important role. Changes in treeline structure and position will probably not follow a common pattern but are likely to be idiosyncratic and species-specific (Dullinger et al. 2004). The effects of species eco-physiological processes, competitive interactions among species, and the expression of climate across rugged topography make the biotic response of alpine treeline potentially complex.

Can variations in the underlying physical environment account for the spatial patterns at the forest-alpine ecotone, or are biologically mediated feedbacks part of the explanation? Feedbacks between trees and their physical environment are positive if the first can modify the environment in their own favour. Negative feedbacks could arise for instance if canopy shading lowers soil temperature to a point of creating unfavourable

thermal conditions for tree growth. Such feedbacks could strongly influence spatial patterns at a local scale.

The physical environment, topography, soils and geology, together with disturbance such as fires, avalanches and landslides, all interact with climate in complex ways to create alpine boundaries. Whether treeline shifts are sensitive indicators of climatic change or not must be determined in each particular situation. The variability in the alpine ecotone elevation may be due to combinations of variability in macro-climate, microclimate, topography, and snow and debris avalanches, plus competition factors between species.

It has been asserted that global warming in mountain regions will be evident from upward migration of the treeline and that this measure can be used globally to track rates of climate change. Several reports show an increased growth of established trees and saplings within the alpine belt, which, in places, has extended the tree limit by ca. 100 m (Kullman 2002). The position of the treeline is therefore affected by complex interactions with past and current climates and various disturbances (Hofgaard 1997, Körner 1999). Several climatic indices, such as summer mean temperature and temperature sums, are related to treeline position, at least over large scales (Körner 1999, Grace et al. 2002), but to assign causal factors linking climate and treeline position has been proved a difficult task. Although it is clear that climate plays an important role, other processes are also important, such as soil conditions, winter desiccation, seed limitation, and competition from established ground vegetation (cf. Dullinger et al. 2004). These factors, together with the carbon balance of the established trees, should be included in a dynamic model of tree growth at treelines (Cairns and Malanson 1998).

Four hypothesis have been advanced pointing to different mechanisms which could dictate a climate driven transition from forest to the alpine communities. These are resistance to cold stress, mechanical limitations, reproductive handicaps and the carbon balance of trees (Körner 1998). All explanations recognize multiple causes but have different emphasis. Stature-related hypotheses involve the problems that a large plant encounters when resources are spatially and temporally limited, exposure of terminal buds, or/and photosynthetic tissue to damage. Growth-related hypotheses emphasize the high respiration costs of a large woody plant leading to a negative carbon balance. Reproductive handicaps focus on the mechanisms of seedling establishment and the growth of saplings and their strong dependence on ecological facilitation (Smith et al. 2003).

Tropical alpine treelines

Some processes, like snow avalanche paths and debris flows which operate in temperate mountains, do not occur at equatorial latitudes. This is so because the snow line is relatively high, at about 4700 m in the northern Andes, which is more than 1000 m above the mean location of the timberline. There is no snow accumulation either, since snow never reaches the alpine ecotone, only occurring, rather infrequently, above 4000 m as a thin snow cover that only lasts a few hours. Soil freezes down to only just below the snow belt, hence mobile soils occur well above the treeline. Strong, cold winds are mostly absent. Therefore, tropical treelines occur under conditions of negligible frost risk,

with hardly any wind and in total absence of snow damage. Freezing temperatures are not frequent, while average temperature conditions are well above the temperatures harmful to plant tissues. Extreme minima however may affect the survival of buds and other meristematic tissues.

In tropical American mountains from Mexico to Ecuador treeline elevation ranges from 3400 to 4000 m. But all along the Andes one of the main problems is the definition of the treeline since there is a wide altitudinal difference between the upper boundary of the montane forest and the highest elevation reached by isolated forest patches where just two or three species of low trees grow, mainly species of *Polylepis, Gynoxis , Escallonia* and a few others. Two main hypotheses have been advanced for the occurrence of these forest patches well above the continuous forest line. One postulates human action as the main factor with a thorough deforestation of the uppermost forest belt which nowadays is restricted to isolated patches within the alpine belt. Accordingly, the páramo is mainly man-made and its thermal conditions are suitable for tree growth, while the *Polylepis* patches are the potential upper timberline (Bendix & Rafiqpoor 2001). The alternative hypothesis is that *Polylepis* has special microhabitat requirements for establishment, growth and survival and hence forest patches occupy habitats with milder climatic conditions than the surrounding páramos (Simpson 1986).

The *Sierra Nevada de Mérida* boundary

The alpine treeline ecotone in the *Sierra Nevada de Mérida* is characterized by the presence of trees advancing upslope into the páramo, either as fingers or tree islands (Fig. 14. 1). Moreover, well above the continuous timberline of the lower montane forest, isolated groves of *Polylepis sericea* occur forming a second and higher discontinuous line of tree growth (Monasterio 1980). Of the different explanations about the position and nature of the timberline**, t**he stress hypothesis postulates that low temperature limits tree growth by direct frost injury to plant tissues. If this is the case, seedlings and juveniles with frost injury must occur above the actual treeline. Up to now this has never been reported in the Venezuelan Andes. It is also possible that tree seeds are found in the soil but they do not germinate beyond the continuous forest cover because of soil or air temperature limitations. If competition is the main mechanisms selecting against tree growth within the alpine vegetation, with seedlings or juveniles not succeeding in competition with high altitude species of shrubs, grasses or herbs, mortality of tree seedling above tree line would have to be found.

Figure 14.1. The montane forest-páramo boundary at the Sierra Nevada National Park, Mérida, Venezuela. The forest advances over the open vegetation on the warmer slopes.

According to the carbon balance hypothesis, seedlings and juveniles stop growing due to a negative carbon budget under low temperature conditions. Trees would be more sensitive to low temperatures than other alpine plant forms, because of the high maintenance costs leading to a negative carbon budget. This hypothesis could explain the decreasing tree height with elevation. Some indications concerning this behaviour have already been reported for *Polylepis sericea* and other important montane tree species (Goldstein et al. 1994, Rada et al. 1996) (Figures. 14.2 and 14.3). Whether such limitations actually amount to a global driver of the sub-alpine forests distribution will be analysed in our CRN by determining the temperature-dependence of the carbon gains of different plant functional types within the woody component of the system.
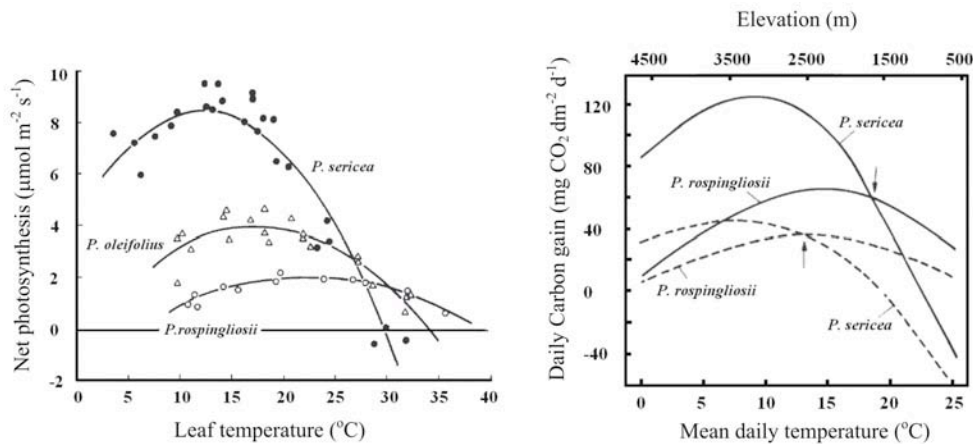
Figure 14.2. Net photosynthesis and carbon balance at different temperatures of three dominant tree species in the Venezuelan Andean forests: Podocarpus rospigliosii, Podocarpus oleifolius and Polylepis sericea. The optimum temperature follows the elevation range of each species. From Goldstein et al. 1994.

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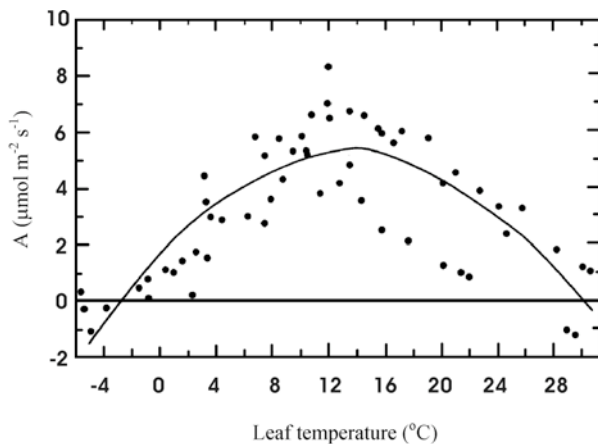
Figure 14.3. Photosynthetic response to leaf temperature of Polylepis sericea. Carbon assimilation peaks at leaf temperatures ranging from 8 to 20ºC, but a positive Carbon balance is attained even at –2ºC. Data from Rada et al. 1996.

The landscape configuration within the ecotone appears strongly controlled by geomorphology and topography, interacting with climate. In this respect landforms are of high importance, as they control the high spatial variability of topo- and micro-climates in mountain areas. The prediction of the consequences of climatic variability on the ecotone landscape, both in terms of configuration and composition, is essential for modeling future ecosystem trends at the ecotone boundary. There are two important questions: 1- which are the climate conditions at and near the treeline?, and 2- how are these average conditions modified by local, relief-related factors? At an elevation of 3550 m, in the *Páramo de Mucubají*, in the *Sierra Nevada* National Park, ca. 300 m above the treeline, mean air temperatures remain close to 5ºC all the year (annual mean 5.4ºC), whereas mean minima during the four dry months reach –1º to 1ºC, being above 2ºC for the rest of the year. Absolute minima range around –2ºC, except during the dry season when they may fall to somewhat below –8ºC (Azocar & Monasterio 1980). At this páramo site a mean of 81 frost days per year has been registered (1967-1975), with 14 to 22 frost days in each of the four months of the dry season and 0.1 to 3 days the other months. At the forest ecotone down slope from Mucubají, with a similar seasonal climate, mean annual temperature is 7.9ºC (8 years).

La Aguada, also in the *Sierra Nevada* National Park at 3450 m, just in the alpine ecotone but with a much rainier climate than *Mucubají*, shows an annual mean temperature (4 years) of 7.1º C, with slight oscillations along the year. Mean minima are above 0º C, and there is less than one frost day per year (2 days in 3 years). Extreme minima at the forest ecotone are above – 3ºC. Six hundred meters upslope, already within the páramo, annual mean temperature is only 3º C, while 1000 m below *La Aguada*, within the montane forest, it reaches 12.9º C. Rainfall gradients with elevation are also sharp on this mountain slope, with decreases up to 40 to more than 50 mm per 100 m elevation. According to these data the thermal conditions at the alpine ecotone (3200-3600 m) are not so extreme, with monthly means around 7º C all the year, and rather

exceptional frost days. But these conditions rapidly change upslope being much more severe at the páramo, and still more extreme during the dry months in highly seasonal climates.

The thermal conditions faced by the vegetation heavily depends on topography but may also be modified by the plant cover. At *Mucubají*, both effects are noticeable. On the one hand, the eastern slopes are relatively warmer than the west-facing slopes because of the diurnal cycle of cloudiness. The net effect of contrasting E-W slopes may result in a difference in mean temperature of 2.9ºC, equivalent to an altitudinal variation of about 500 m, and double the number of frost days. On the other hand, tree shading may play an important role altering the local climate as happens below the *Polylepis* forest canopy, where mean temperatures average those on both slopes under páramo vegetation at the same altitude, but the extremes are significantly moderated, having higher minima and a much reduced number of frost days. Air and soil temperatures, soil water content and solar radiation, across the forest-páramo boundary, are needed to disentangle the environmental drivers determining the occurrence of one or the other ecosystem and the precise location of their boundaries under natural conditions. The effect of elevation, slope and aspect, together with the influence of plant cover, will allow a further understanding of their limits and their possible displacements under different scenarios of climate change.

There may also be biotic-induced feedbacks, both positive and negative, at the individual, patch, and landscape scales. Strong positive feedbacks are necessary to ameliorate the basic conditions in the páramo to allow trees to establish and grow; potential carbon balance is otherwise too close to zero. Specific mechanisms for establishment of individual-level positive feedbacks/facilitation have been well documented for the alpine treeline. The shape and position of each ecosystem patch in the landscape is assumed to largely determine the outcome of the feedbacks operating at all levels. The landscape configuration is a necessary integrative level to make predictions about the ecotone dynamics under different scenarios of global change.

Altitudinal vegetation belts and land use

Land use dynamics are closely linked to environmental conditions which also determine the occurrence of natural ecosystems. Environmental change, which displaces natural boundaries, may also cause important changes in the spatial patterns of land use and land use change. The influence of these changes on land use is already noticeable in semiarid environments, where the extension of rain-fed crops has proven sensitive to changing rainfall patterns. It may also be of great importance on tropical high mountains where the main forms of land use closely follow the spatial patterns of temperature and rainfall (Monasterio 1980).

In the northern Andes one key land-use boundary is the upper limit of crops, which may reach ca. 3800 m asl, roughly coinciding with the 5°C isotherm. Below this limit, the spatial arrangement of the different crops (mainly cereals, tubers and bulbs) and of secondary succession after cropping seem to obey physical-environmental factors such as frost frequency and insolation, which depend on the interactions of general patterns of temperature and atmospheric circulation, with terrain features such as aspect, slope and

elevation (Sarmiento et al. 2003). Some other uses extending over the humid summits of the tropical Andes are animal husbandry and commercial forestry. Animal husbandry takes different forms according to elevation. At the forest level grazing exploits deforested soils by introducing exotic forages and supports an acceptable secondary productivity, at least for a certain time, although the system is vulnerable to the erosion triggered by cattle trampling. At páramo elevation, animal husbandry is significantly more extensive, exploiting either grassland communities or fallow lands whose natural productivity is low (Abadin et al. 2002). The impacts of climate change on animal husbandry at these different elevations are expected to be quite different since the productivity and stability of the grasslands depends on different factors of the biophysical environment.

The history of the human occupation of the Venezuelan páramos and montane forests includes the pre-Hispanic use of high altitude environments for Andean grains and tubers, the introduction of wheat and other Mediterranean crops by the Spaniards, and nowadays an intensive use of the best soils with a diversified horticulture (Sarmiento et al. 1993). The montane forest zone was largely untouched until the last decades of the 19th century, when the advance of the coffee system over the medium elevation slopes, below the cloud forest belt, encouraged the arrival of settlers to the region. However, a widespread deforestation of the forest below the páramo belt, only occurred a century later, when pastures were established for milk production. Interestingly, intensive agriculture has largely developed on the colder and drier extreme of the montane forest-páramo transition, while more extensive use through cattle raising has dominated the cloud forest belt. This shows how the effect of climate factors is context-dependent. Although one might anticipate temperature to be the main physical driver of land use, in the cloud forest environment lack of insolation and water excess seem to be more important constrains for the cold-temperate crops prevailing in the páramo.

Climate change may strongly influence species distribution and, thus, the structure and function of ecosystems. Global meta-analyses have documented significant range shifts towards the poles and to higher altitudes in response to warmer climates, earlier springs, and milder winters (Parmesan and Yohe 2003). These changes may have significant effects on the structure and function of ecosystems, as new species assemblages may form (IPCC 2001), and therefore also on conservation values and human utilization patterns. Effects may include changes in primary productivity, extinction of rare species, invasion by more temperate species, and afforestation of previously non forested sites (IPCC 2001). Natural resource managers need to discuss how to adapt to these changes, developing management strategies for ecosystems. Nevertheless, such a discussion will only prove effective when based on solid ecological understanding.

Final remarks

The study of ecotones across a wide range of spatial scales may shed light on the key drivers regulating functioning and dynamics of the neighbouring ecosystems. When boundaries are easily determined, as in the case of structurally-contrasting ecosystems, a

detailed determination of the environmental and other factors controlling the distribution of these ecotones may be possible.

Although treelines in mountains have been one of the most thoroughly analysed ecosystem boundaries, the complexity of the interactions between species and external factors is so great that even the location of these boundaries is not completely understood. In tropical alpine timberlines many of the factors that are important in temperate mountains do not exist. This may reduce the number of external agents acting upon the upper extension of montane forests. In the *Sierra Nevada de Mérida* the alpine ecotone is primarily determined by low temperatures and these in turn depend on elevation and topography. The precise characterization of the different local climates near and above the treeline will be one of the main goals of the new CRN project in the Venezuelan Andes.

Of the different hypothesis advanced to explain the mechanisms involved in the upper treelines, carbon balance of trees seems to be important in the few analysed tree species, while frost injury seems to be less widespread. The effects of low temperatures on plant establishment has scarcely been considered and be one of the main critical factors to be explored.

As land use is closely related to the distribution of natural ecosystems, changes in uses may be expected if the ecosystem boundaries undergo significant displacements. In the case of the *Sierra Nevada de Mérida*, an upward extension of the high elevation dairy use may be expected as well as a further upward progress and intensification of agriculture in the páramos. The analysis of such changes should proceed by two different, yet complementary ways: (1) by identifying those controls of the physical environment acting upon both, natural and man-made ecosystems, and (2) by determining which processes of the natural ecosystems are of key value for maintaining the appropriate biophysical environment for a given land-use. Needless to say, the second approach is more challenging and remains largely unexplored. In the context of the IAI CRN 2005 project we intend to translate the common controls of (1) into the more interactive picture of (2).

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15

Deforestation and restoration of a tropical dry forest in the Chorotega region, Costa Rica.

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Little has changed in terms of conservation and sustainable management of tropical dry forests (TDF) since D.H. Janzen (1986) declared that the Mesoamerican dry forests were the most threatened ecosystem in the region. Redford et al. (1990) and Mares (1992) showed that if species richness is the key factor for prioritizing areas for conservation, the TDF should receive attention at least equal to that given to the rainforests. However governmental policy and funding agencies seem to have a bias towards tropical rain forest conservation and have promoted land development in other ecosystems such as the TDF without much thought about their devastation. In order to counter the loss and degradation of the TDF, Sanchez-Azofeifa et al. (2005a,b) advocated a new multidisciplinary approach for conservation models.

Sanchez-Azofeifa et al. (2005b) define the seasonally dry forest as a vegetation dominated by deciduous trees located in regions with a mean temperature >25ºC, a total annual precipitation range of 700-2000 mm and three or more dry months (precipitation <100 mm). A mix of deciduous and evergreen species gives the dry forest a phenological complexity not encountered in tropical wet forests (Burnham 1997). The seasonally dry tropical forest comprises nearly half of all tropical forests (Brown and Lugo as cited by Murphy and Lugo 1986). In Mesoamerica TDF ranges from the Pacific Coastal plains of Mexico and the Yucatan to the Pacific Coast of Panama covering approximately 26% of the total surface area with various deciduous vegetation types (Murphy and Lugo 1995). The true extent and the degree of habitat fragmentation of the TDF have always been in debate and no complete estimate exists (Sanchez-Azofeifa et al. 2005b).

Functional degradation of TDF occurs as biodiversity declines to moderate or low levels, whereas under recuperation, ecosystem processes level off between intermediate and high levels of biodiversity and will not be affected by further increases (McGrady-Steed et al. 1997). The prevention of functional deterioration that follows biodiversity loss is a strong reason for conserving relatively intact ecosystems, and for promoting the restoration of degraded ecosystems (Marks and Borman 1972, McGrady-Steed et al. 1997).

Understanding the causes of TDF disturbance and their cascading effects on many components of this ecosystem are key to identifying negative effects on biological resources and human development, and for elaborating policies and strategies for conservation and sustainable management (Sánchez-Azofeifa et al. 2005b). Our current understanding of the impacts of land use/cover change on human dominated landscapes is strongly linked to a clear understanding of the socio-economic and biophysical forces driving land use and land cover change. These forces, acting at different scales (from the production land unit to the regional and international levels), contribute to regional environmental deterioration trends. In many cases, these trends cannot be fully

understood because of a lack of spatial databases of socio-economic and biophysical landscape characteristics (Arroyo-Mora et al. 2004).

Costa Rica with a total area of only 51,000 km^2 encompasses approximately 6% of the world's biodiversity which has been threatened for decades (de Mendoza and Jimenez 1995, Wendland and Bawa 1996, Sánchez-Azofeifa 2000) by deforestation. The Chorotega region was the first and most deforested region in Costa Rica (between 1940 and 1980), due to its favorable topographic and climatic conditions for transformation to pasture and agricultural land (Boucher et al., 1983, Ewel 1999, Arroyo-Mora et al. 2004). Yet Arroyo-Mora et al. (2004) showed an extraordinary rate of forest restoration (+4.9% per year) over the last two decades. The causes of this restoration are a myriad of regional, national and international factors that both lowered deforestation and increased restoration rates during this period. We discuss the causes associated with the deforestation and restoration processes in the Chorotega region since 1960 in a science-policy nexus essential to landscape management decisions. The goal of this chapter therefore is to explore the linkages between socio-economic policies and conservation efforts in the Costa Rican TDF. We must understand the forces that drive land use/land cover change and act at various scales to contribute to the conservation or degradation observed in these ecosystems (Sanchez-Azofeifa et al. 2005a, b). Without a thorough knowledge of these forces and the ecosystems affected, it is unlikely that any sustainable development solution will be found. Hence substantial funding and research efforts to improve our knowledge of TDF diversity and functioning will be needed (Sanchez-Azofeifa, 2000). Until recently, serious limitations in quantitative detection and classification of TDF by remote sensing have hampered conservation strategies.

Background

We considered a comprehensive forest cover database with available social statistics and policy reconstruction over a 40 year period (1960-2000) of the Chorotega Region of Costa Rica. This region comprises a climatic gradient from very dry to moist tropical forests, and covers 20 % of the national territory comprising most of the Guanacaste province (Fig 15.1).

Datasets for forest cover assessment were compiled by Arroyo-Mora et al. (2004) for the 40 year period based on four years: 1960, 1979, 1986 and 2000 (Fig. 1). For 1960 the forest/non-forest maps were derived from 1:40,000 aerial photographs acquired by the US Army between 1955 and 1965. The 1979 map is from a 1:100,000 scale land cover map produced by the Costa Rican National Meteorological Institute (IMN) corrected by Arroyo-Mora et al. (2004) using two Landsat Multispectral Scanner images acquired between 1978 and 1979. For 1986 and 2000, maps were produced based on the interpretation of Landsat Thematic Mapper TM 5 and ETM+ 7 satellite images (TSC-CIEDES-CI-FONAFIFO, 1998, U. Alberta and CCT 2002, Arroyo-Mora et al. 2004). Accuracy has been estimated at 90% overall for the 1986 dataset and 89% for the 2000 data set (TSC-CIEDES-CI-FONAFIFO, 1998, U. Alberta and CCT 2002).
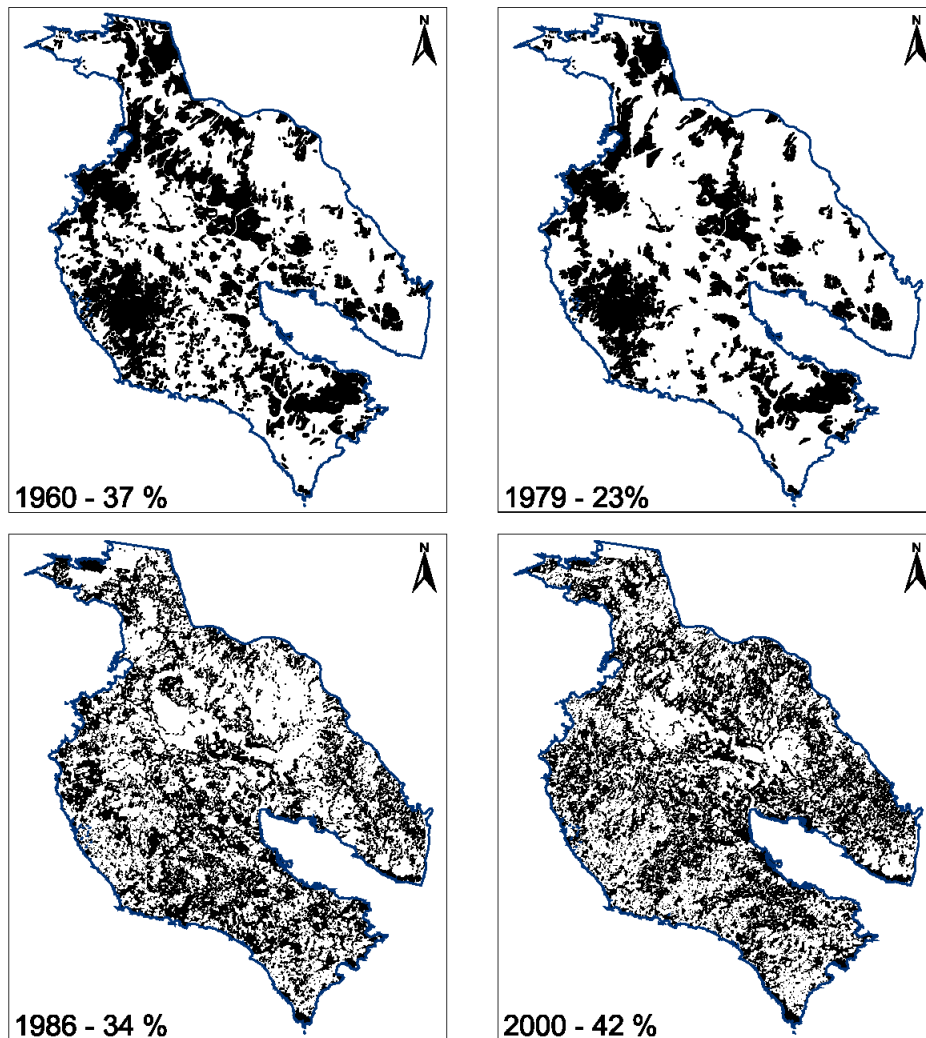
Figure 15.1. Forest cover maps for the Chorotega region, Costa Rica, from 1960 to the year 2000. Dark areas correspond to forest cover (*Source of Information: Earth Observation Systems Laboratory, Department of Earth and Atmospheric Sciences, University of Alberta*)

Chorotega Dry Forest Cover Dynamics from 1960 to 2000

As indicated in Figure 15.1, forest covered 37% of the of the region in 1960, 23% in 1979, 34% in 1986 and 42% in 2000. During the period of 1960 to 1979, Arroyo-Mora et al. (2004) found an annual deforestation rate of 2.8%. And, for the subsequent two

periods (1979–1986 and 1986–2000), they found an increase in forest cover of 1.6% per year and 4.9% per year, respectively.

Based on a new forest cover assessment of the Chorotega region for the year 2005 aimed at classifying the forest cover into three stages of succession, we estimate that of the 5,242 km^2 (52% of the total area) of forest cover detected for the year 2005, 64% is in a late successional stage or mature forest, 16% is in an intermediate and 20% in an early successional stage (Sánchez-Azofeifa et al. 2006). We also found significant differences in the structure of these forest stages in 26 (0.1ha) field plots in the Santa Rosa National Park (Kalascka et al. 2004). Neglecting successional stage in the assessment of the value of secondary TDFs (in terms of carbon sequestration and environmental services) can result in errors in the millions of dollars (Kalacska et al. 2008). If the rate of forest regeneration remains relatively constant from 2000-2010, a carbon gain of over 1,000,000 Mg is forecast with an estimated value in excess of $US 500,000 (US$ 29.4 / ha) for that region alone (Kalacska et al. 2008).

Table 15. 1. Description of the three successional stages in the dry forest of Sector Santa Rosa, (200 –300 m elevation), mean values with 1 standard deviation of the forest structural characteristics (height, basal area, density and number of species) and the Holdridge complexity index (Adapted from Kalacska et al. 2004).

Forest Stage	General description	Height in m	Basal Area in m2/ha	Density, number stems/0.1 ha	Species Density, number sp/0.1 ha	Holdridge Comple-xity Index
Early	1 layer. High percentage of deciduous trees. Many shrubs, small trees with grasses and bare soil in open areas	7.5±2.2	11.7±5.4	112±64	15±7	28±36
Intermediate	2 layers. Superior layer of canopy composed of fast growing deciduous species. Lianas, and shade tolerant species compose second layer. Presence of both deciduous and evergreen species	10.3±3.4	21.4±6,8	130±35	29±5	68.6±57.7
Late	2 layers. Superior layer of canopy composed of fast growing deciduous species. Lianas, and shade tolerant species compose second layer. Presence of both deciduous and evergreen species	15±2.2	30.1±6.5	107±42	29±7	159±57

Deforestation and Restoration driving forces in the Chorotega Region 1960-2000

International Economic Forces

The main anthropogenic driver behind changes in land use/cover in the Chorotega region has been the clearing of forest for cattle pastures to provide beef exports to the United States, initiated in 1957 (Arroyo-Mora et al. 2004, Quesada and Stoner 2004). This forest conversion was encouraged by the Costa Rican government (supported by the World Bank and USA-AID) and international development organizations with colonization policies and low interest bank loans. As a result the deforestation rate in Costa Rica was >50,000 ha/year during the late 1960s and early 1970s (Myers 1981, Parsons 1983, Solórzano et al. 1991, Lutz and Martinez 1993, Sánchez-Azofeifa 2000, Arroyo-Mora et al. 2004).

Costa Rica was one of the leading Latin American beef exporters, supplying 5% of beef imports to the United States of approximately 30,000 ton/year by 1977 while also expanding exports to Israel and Venezuela (Boucher et al 1983, Arroyo-Mora et al. 2004). Following changes in international beef prices, cattle grazing reached a peak in 1972 with a total of 2,226,000 heads, 40% of which was in the Chorotega Region (Parsons 1983, Montenegro and Abarca 1998, Ibraham et al. 2000, Arroyo-Mora et al. 2004). After 1992 with declining international beef prices the number of cattle declined to approximately 1,900,000 heads (Ibraham et al. 2000, MAG 2000, Sanchez-Azofeifa 2000). As a consequence of which cattle pastures were progressive abandoned.

National Forces

Land Colonization Policies: In 1962 the government launched a massive land colonization program under the direction of the Instituto de Tierras y Colonización (ITCO). ITCO assigned land titles to those that had colonized new land since 1941 and thereafter promoted colonization of an additional 170,000ha 1979. About 25% of the new colonization was in the Chorotega Region. Farmers had to show "land improvement" in order to claim land titles for the new land. These "improvements" were understood to be forest clearing (Hall 1984, Watson et al 1998, MINAE 2002). In 1969 the first forestry law was approved and subsequently, in theory, no further forest clearing was allowed. Nevertheless, the new Forestry Service was unable to control the massive continued deforestation in the county, particularly in the Chorotega region.

Road network: In conjunction with the policies of colonization of new land the government was required to provide basic infrastructure for rural development in the form of a road network. The road network increased exponentially during this period: 1,500km in 1950, 6,400km in 1970, 10,500km in 1978, 35,300 km in 1985 and 35,300km in 2000 (Flores 1982, Hall 1984, MIDEPLAN 2004) which facilitated colonization of new land.

Timber harvesting: The constant improvement in the road network was an incentive for the timber industry. Logging of precious woods, in particular, was a popular option for generating additional income while clearing the forest for colonization or grazing. Many authors argue that the timber industry was not the main cause of deforestation in Costa

Rica, but an expected consequence of land colonization and cattle ranching (Hartshorn 1982, Ramírez and Maldonado 1988, Quesada-Mateo 1990, Harrison 1991). A study from CCT-WRI (1991) estimated that between 1963 and 1989, forest clearing was 15.7 million m3 of timber, of which only 10% was selectively harvested while the remainder was left on the fields or burned.

Forestry and conservation policies: Between 1970 and 1980, the National Park Service created most of the Protected Areas of Costa Rica as a preventative measure against the deforestation of important ecosystems and watersheds that protect valuable water resources. During this period the Costa Rican government created 34 protected areas covering 12% of the national territory. From 1980 to 1990 the number increased to 86 protected areas representing 25% of the territory. It is estimated that Costa Rica invested more than US$1,000 million in the establishments of this network of conservation areas (Castro and Arias 1998).

In 1986, during the decline in cattle ranching, the government approved a new forestry Law No. 7032. This new law redefined the forestry sector by a) promoting a national forestry plan along with a set of economic and legal incentives to promote sustainable forest management and reforestation, b) forbidding forest clearing on land not suitable for agriculture, c) forbidding the burning of forest and d) supporting the consolidation of protected areas. In 1996 another forestry Law No. 7575 introduced the legal and institutional framework for the payment of environmental services. This novel concept was of paramount importance for forest conservation on private lands (Castro and Arias 1998, MINAE 2002).

Other national factors

The decline in cattle production is also linked to policies implemented after 1970 to transform the national economy from agrarian to industrial. Most of these forces reinforced, often by coincidence, the slowing of deforestation and the intensification of the restoration.

In general the Chorotega Region experienced a sustained transformation of its production and social structures since 1950 (Table 15.2) (MEIC 1954, 1966, 1974 a, 1974 b, 1975, 1978, 1986, 1987 a, 1987 b, SEPSA 1990, INEC 2000, 2002). For instance, in 1950 the agricultural sector occupied 80% to the total labor force of the region. In 2000 that figure had decreased to 9%, a clear indication of the extent of economic diversification. In 1950 only 10% of the houses in the region were connected to the electrical grid. By 2000 that figure had increased to 93%. This increase had a great impact on the firewood and charcoal demands for cooking. In 1950, 78% of the houses used firewood or charcoal for cooking while in 2000 this figure was only 23%. The urban population of the region increased from 14% in 1950 to 42% in 2000.

Tourism has been one of the new economic activities that reshaped the region (ITC, 2004, Quesada and Stoner 2004). Official records indicate that visitor numbers in Costa Rica increased by 16,000 annually between 1966 and 1983. After 1986 the annual increase of new visitors was an average of 60,000 and by 2000 total annual number of

visitors was 1,238,000. The annual estimated income for the year 2000 from the tourism sector was US$1.2 million, the most important national income and source of employment. The Chorotega region is the most important tourist destination due in part to ecotourism and the popularity of its beaches. In 2000, the Chorotega region accounted for 24% of the Costa Rica's lodging; surpassed only by the San Jose Province with the capital city.

Table 15.2. Socioeconomic statistics of the Chorotega Region between years 1950 and 2000. Notes: a) Information sources: MEIC 1987, 1986, 1978, 1977, 1974, 1966, 1954, SEPSA 1990, INEC 2000, 2002. b) Data correspond to the Guanacaste Province, that occupies most of the Chorotega Region

Variable	Year				
	1950	**1963**	**1973**	**1984**	**2000**
% Urban population	14	15	24	27	42
% Rural population	86	85	76	73	58
% Houses with electricity	10	16	31	64	93
% Houses cooking with firewood or charcoal	76	95	81	69	28
% Agricultural employment	80	--	58	50	9

Another important factor that stabilized the economy of cattle ranching has been the introduction of technological improvements since 1990 (MAG 2000, Ibraham et al. 2000), most importantly, the introduction of new grasses (mainly *Bracharia sp*) that are better adapted to the prolonged dry season and are more productive and nutritious than the traditional Jaragua grass (*Hyparrhenia rufa*). A second factor has been the improvement in the genetics of the national herd, by introducing new breeds that produce a better quality and greater quantity of meat in less time. The combination of these two factors has allowed many farmers to continue animal production on the most productive portions of their farm, leaving more degraded lands to natural regeneration. Many of these farmers have also taken advantage of the Payments for Environmental Services and hence are able to benefit economically from reforestation or conservation of secondary forest patches.

Implications and conclusions

We conclude that deforestation in the Chorotega region followed patterns common to many tropical countries. In Costa Rica and in particular in the Chorotega region, the regional economy was diversified and the rural society was transformed into an urban society. This diminishes pressures to clear forest and promotes restoration of degraded grazing lands. Since beef export was the driver for pasture expansion, a decline in the international beef price affected land use changes. This change of direction was

coincidentally supported by other policy and economic changes, such as tourism, technological improvements in ranching and the implementation of new forestry and conservation polices. Without the concurrence of these new policies, forest cover restoration would not have happened at the same rate because farmers would most likely have continued to use their land for either cattle or other agricultural alternatives. Unexpected economic incentives such as payments for environmental services and ecotourism occurred at the right time to set aside degraded pasture lands for restoration, allowing farmers to concentrate improved cattle grazing in the most productive land units.

Many international development institutions and politicians are inclined to regard the notable forest recovery of Costa Rica, and the Chorotega region in particular, as the sole validating result of a successful implementation of forestry and conservation policies. But in reality, slowing deforestation and improved forest restoration have been the result of many factors co-occurring at the right time. Nevertheless, we do believe that forestry and conservation polices were established at the right time to take advantage of the economic and social changes taking place.

There is a need for continuous and systematic efforts to understand and integrate information about TDFs in the Americas in three contexts: a) conservation biology, b) land use and land cover change on the agricultural frontier and c) local and national development policies that contribute to the degradation and restoration of TDFs. For these reasons, the IAI is funding a research project on Human, Ecological and Biophysical dimension on tropical dry forest (CRN2_021) to bring together researchers in conservation biology, ecology and evolution, remote sensing and geographic information systems, sociology, anthropology, policy analysis and forestry. The CRN aims to develop a comprenhensive understanding of the status of both primary and secondary TDFs.

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16.

Thinking outside the box: Tropical conservation in both protected areas and the surrounding matrix

Juan J. Jiménez-Osornio, Veronique M. Rorive, Arturo Gomez-Pompa, Holm Tiessen, and Michael F. Allen

Biodiversity worthy of protection is often presumed to be a characteristic only of wilderness areas. This view results in the creation of reserves that restrict or even exclude human activities. Evidence supporting this assumption, based on data from limited groups of organisms, is incomplete. Valuable biodiversity elements may be overlooked and therefore lost in conservation efforts. The greatest amount of biodiversity for many groups of organisms exist outside protected areas in regions inhabited, used, and modified by traditional cultures and local inhabitants. These areas constitute an ecological mosaic that may include a wide diversity of ecosystems. Our hypothesis is that developing a means to integrate such areas into regional biodiversity planning could protect large numbers of species in the long-term. In 1999, the World Bank and the Mexican Government proposed the establishment of two conservation corridors: Celestún-Ría Lagartos and Calakmul-Sian Ka'an in the Yucatan Peninsula. While the importance of corridors is not a new concept in theory or practice, we here suggest that specific management strategies that focus on a mosaic of land uses by the people living in those corridors should be considered. Incorporating traditional agriculture, agroforestry, and natural reserves into a comprehensive management strategy could result in an improved design for the protection of biodiversity and development. Analysing planning and monitoring this initiative requires the integration of the social and natural sciences with a cross-sectoral approach that includes public policy and local communities in the study of land use patterns and regulatory processes. The aim is to (1) maintain ecosystem patterns and processes through the management and coordination of both established protected areas and the surrounding matrix, and (2) identify economical and environmentally sustainable livelihoods.

Agrobiodiversity in the Yucatan Peninsula

Mexico has used the establishment of protected areas as a primary strategy to guard its extraordinary biodiversity. A substantial investment by Mexican federal and state governments and various national and international conservation agencies has resulted in a suite of large reserves throughout southeastern Mexico. Twenty-five percent of Mexico's biosphere reserves are located in the Yucatan Peninsula. Yet we know that even greater biodiversity exists outside of protected areas; in regions inhabited, used, and modified by traditional cultures (Gómez-Pompa et al, 2003) and local inhabitants (de Jong, 1997). These collective areas constitute an ecological mosaic that includes an as yet rarely recognized high diversity of ecosystems. We postulate that developing a means to

integrate these areas into regional biodiversity planning could protect large numbers of species (Gómez-Pompa et al, 2003).

The Mesoamerican Biological Corridor project, a transnational initiative in Central America and southern Mexico (Kaiser 2001), supported by the World Bank and governments of these respective countries, is designed to conserve biodiversity by linking protected areas from southern Mexico to Panama using a corridor of natural and "restored" habitats. This project includes the establishment of two portions linking reserves in the Yucatan Peninsula from Celestun to Ria Lagartos and from Calakmul to Sian Ka'an (Figure 16.1).
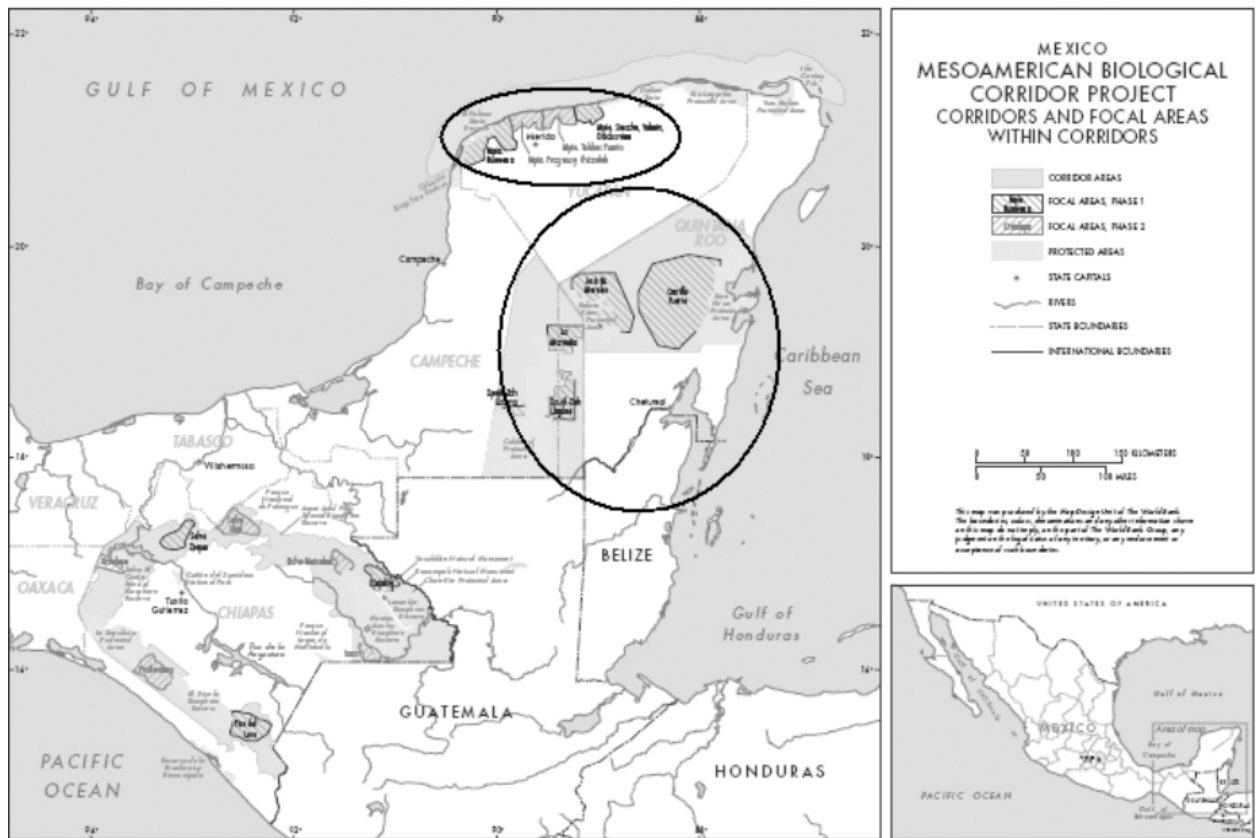
Figure 16.1. Mesoamerican Biological Corridor in the Yucatan Peninsula delineating the proposed corridor linking Celestun with Ria Lagartos and Calakmul with Sian Ka'an.

While the importance of corridors is not a new concept in theory or practice, strategies that utilize the mosaic of land uses created by the people living in those corridors has not been developed. Projects such as the Mesoamerican Biological Corridor have failed to consider all stakeholders and actors. This has resulted in slow adoption and minimal progress to date. Furthermore, interactions among governments, agencies and local producers have been difficult.

Currently, potential corridors in the Yucatan Peninsula are rapidly being converted from secondary forest to agriculture and cattle ranching. In addition, there are

increasing frequencies of fires and hurricanes (Allen et al., 2003.; Boose et al., 2003) that impact within and outside of protected areas and are rapidly converting a major part of the region to a state of arrested succession (Mizrahi et al., 1997) comprised of young secondary forest with scattered individuals and patches of remaining mature forest. Agricultural development can fragment a matrix of continuous forest punctuated by small clearings of agriculture and settlements into a heterogeneous mosaic with small habitat patches spread across a matrix of developed lands. This matrix consists of lands in slash and burn agriculture and under cattle grazing.

Agroforestry projects, successional habitats, existing mature forest fragments, degraded forests and restoration projects are all critical reservoirs for biodiversity in that they provide habitat and refuge for a unknown number of species (Medellín and Equihua, 1998; Perfecto et al., 2003). Secondary forest in slash and burn agriculture in particular are fundamentally important habitats for conserving and restoring biological diversity (Kammesheidt 2002), for increasing forest cover for wildlife (DeWalt et al., 2003), carbon sequestration, timber and non timber products, watershed protection, and for their potential in linking protected areas. Such agricultural landscapes have been ignored in conservation strategies, and too often are viewed as incompatible with biodiversity conservation. The local inhabitants, primarily Maya *campesinos* (rural subsistence family production farmers), are recognized as the keepers and users of the knowledge in the management of these natural resources (Gómez-Pompa and Kaus, 1998). They have developed a complex management system that integrates its environment at different scales, e.g., home-gardens, slash and burn (*milpa*), and successional vegetation, and have used this approach for millennia (Gómez-Pompa et al., 2003).

Regional conservation strategy

Landscape fragmentation theory suggests that more than 60% of the land area would need to be protected in order to maintain connectedness across a region if protected areas are randomly distributed (With and King, 1999). Lesser amounts of land can still be protected and sustain connectivity if they are chosen to have a low fractal dimension. However, protecting even this lesser amount of land in conservation reserves may not be economically feasible. As can be seen in Figure 16.1, each current reserve is completely disconnected and there is little chance of developing a reserve network even with efforts to design linkages, such as the Mesoamerican Biological Corridor Project. Recent research has demonstrated that all corridors are not alike. Their effectiveness depends on the surrounding matrix and the species of interest. For some species, the boundary comprises its niche. Even the classical pattern of land protection will likely not succeed if the corridor width is too narrow or the corridor is broken by fire or natural disaster, or if animals are small and the length of the corridor extends beyond the dispersal distance.

The first step in creating connectedness between reserves is the recognition and development of land-use techniques that foster linkages. The architecture of agroforestry, for example, may serve as connective or even home range habitat for birds (Greenberg et al., 1997; Reitsma et al., 2001) and be complementary to protected undisturbed forest in habitat management plans for monkeys (Bearder, 1991; Gallina et al., 1996). To make

this effective, it may require that agroforestry lands form a conduit between reserves and are not just randomly placed. Similarly, agricultural practices such as *milpa* fields can rotate through an existing forest matrix resulting in patches of secondary vegetation of different ages and sizes. Careful maintenance of late-seral species may allow such patches to develop the more open understory architecture exhibited by a mature forest (Allen et al, 2003) with greater use by insects and birds (Rotenberg et al, unpublished data).

Often overlooked, small scale community reserves exist throughout the Peninsula, Jiménez-Osornio and colleagues (2004) identified six communities in the state of Yucatan that have community reserves. In the municipality of Calakmul, Campeche, four out of five communities involved in an agroforestry project identified ownership of community reserves (Rorive, 2006). Reserve size and purpose varies from community to community, requiring that additional social and biological studies be made with regard to the structure and purpose of these reserves. The total area in these small-scale reserves is substantial and they together with the extant *ejidal* lands may plausibly serve as corridors between the larger reserves. The challenge is to improve the biological functionality of these small individual reserves, and creating a system that promotes them at biological, socio-economic and political levels.

If reserve connectivity is designed in a scale-free pattern that might allow for random acquisitions of reserves, an optimal system of connectivity will be created when the large reserves (hubs) will have multiple connections with various small reserves (nodes) (Figure 16.2). Increasingly, research has shown that highly stable systems, such as the organization of metabolic networks, the internet, and food webs are distributed in scale-free networks. These patterns appear to have greater resilience to perturbation than randomly-derived connections (Albert and Barabasi, 2002; Barabási and Bonabeau, 2003).
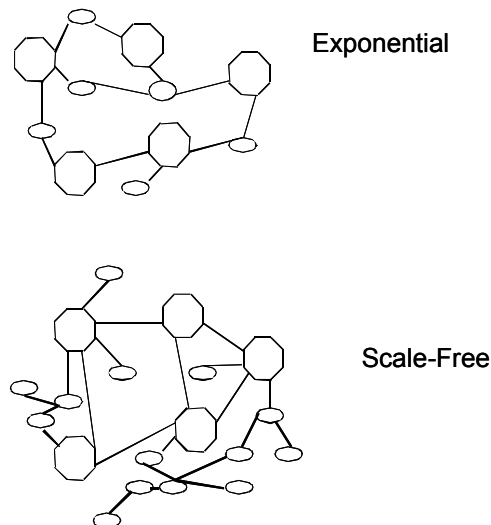
Figure 16.2. Structure of networks of large and small reserves showing a randomly-derived suite of connections forming an exponential decay for the number of links versus the scale-free network with no defined peak in the number of links. The scale-free model has been shown to be more stable and appears characteristic of many biological systems**.**

Ultimately, biodiversity is influenced by the structure and function of the existing landscape as well as by restoration and conservation activities (e.g., establishment of nature reserves, restauration of degraded areas), and agriculture and forestry practices (Figure 16.3). The positive contributions of restoration/conservation and agriculture/silviculture on biodiversity can be amplified by their indirect effects as mediated by their spatial arrangement within the landscape . Biodiversity can be enhanced when any of these activities at smaller scales can be placed so as to maintain or enhance connectivity among natural areas over larger scales, so as to minimize native habitat fragmentation. It is important to recognize, however, that these activities are conducted by people in landscapes inhabited by people. For any large-scale biodiversity maintenance program to be successful, it must include participation by those who are affected. Although these people are frequently called "stakeholders", in many cases they are ignored in the planning and decision-making. Critical to their participation is understanding the socio-economic factors that drive decision processes, from the local (e.g., what does a local farmer consider when deciding where to locate a milpa) to the regional scale (e.g., what might the ecotourism benefits be from selecting among alternate reserve designs). Understanding the socio-economic underpinning of restoration/conservation and agriculture/silviculture provides insight into how to manipulate incentives to optimize both biodiversity and individual and local economic well-being.
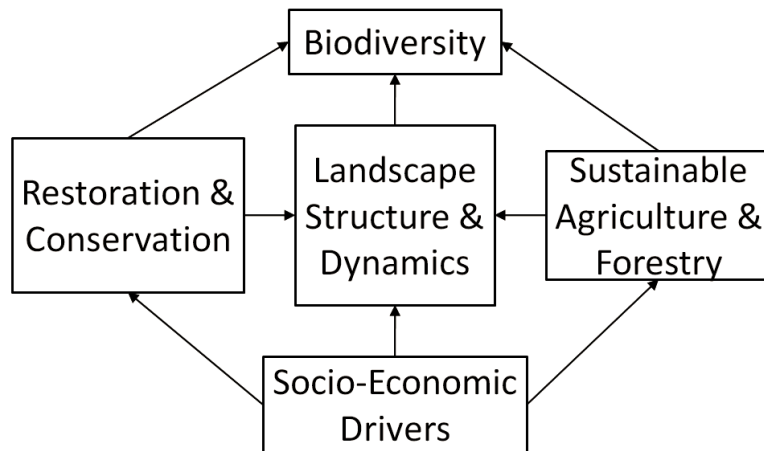
Figure 16.3. Relationships among research foci

These interrelationships imply that a research program that emphasizes only one or two components is unlikely to be fully successful. The challenge, of course, even in an integrated approach such as this is in the development of understanding of the mechanisms that drive these connections; in other words: what do the arrows connecting the boxes in Figure 16.3 actually mean?

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17.

Reverting agricultural lands into native prairie: An emerging option for sustainable management of the mixed grasslands of the Canadian prairie under global change

Chantal Hamel, Michael P. Schellenberg and Juan Carlos Perez

One of man's greatest impacts on ecosystems is simplification such as the reduction of diversity. The Millennium Ecosystem Assessment (2005) reports that many ecosystems are modified to provide a single service: crop production. The Millennium Ecosystem Assessment, furthermore, projects a loss of 10 to 20% of grass and forestlands world wide through conversion to cultivated land by 2050.

Large parts of the Canadian mixed prairie have been converted to annual cropping or seeded with introduced grasses for forage production. Lesica and Deluca (1996) estimated that 6- 10 million ha have been seeded to the introduced cool season grass Agropyron cristatum since the 1930's. In Saskatchewan, A. cristatum was used extensively to prevent continued soil erosion during the drought years of the 1930's. Today, this grass is used to revegetate road sides after construction or repair and is a major forage plant although it has been identified as an invasive species. Areas seeded to A. cristatum have been identified as being lower in sequestered C (Dormaar et al. 1990; 1995; Christian and Wilson 1999) compared to native prairie, in part as a result of monoculture seedings.

There is now a growing interest in removing land from annual crop production and returning to some form of perennial cover. This can be attributed in part to changing climate as well as changing economic realities that make annual cropping unprofitable. In the past, European species have been recommended for forage production, but few of these species have good feed quality under the drought conditions characterizing the second part of the growing season in the mixed prairie ecozone. Recent research has identified the native plant community as an interesting resource for cattle grazing (Jefferson et al. 2005) and the 'Ecovar™' program of Agriculture and Agri-Food Canada in collaboration with industry now provides farmers with seeds of a number of native species. Through this program, seeds of locally adapted genotypes are multiplied and made available for the establishment of native grass stands on soils transformed by agricultural production.

Ideally a complete reconstruction of the prairie ecosystem could be the objective, but neither knowledge nor finances are available for such an endeavor. Herrick et al. (2006) state that sustainability of restored ecosystems depends on processes associated with C, nutrient and hydrologic cycling. A great deal of effort has been expended in re-establishing plant communities but plants are not the complete ecosystem. Restoration of natural disturbances common in grasslands is also important. Klimeck et al. (2006), after surveying 117 grasslands in Europe, found that local management greatly affects diversity. Decreasing fertilization and grazing at a low stocking rate helped conserve

biodiversity. Grazing of restored native plant stands can provide livestock with a source of good quality forage in the dry part of the growing season.

Restoration of ecosystem function requires re-establishment of plant-soil-microbial interactions. In grasslands of the Netherlands and the United Kingdom, Bezemer et al. (2006) observed that plant species and their functional group affected microbial populations, in part through modification of the soil environment by different plants.

Adaptation to aridity involves both the selection of adapted species within taxonomic groups and the selection of an adapted community structure. The re-establishment of locally adapted biodiversity is a first step towards managing the soil-plant system effectively. But more knowledge is required, in particular about the soil, before land managers can implement "best solutions". We believe that the identification and comparison of the dominant processes in natural and restored ecosystems will help identify means for the sound management of lands in the years to come. We also believe that biological diversity will offer tools for the management of principal ecosystem processes. In a context of global change, studies comparing native and managed ecosystems under subhumid to semiarid conditions are undertaken to provide solutions for the large areas of land, where greater aridity is expected in the near future (Fuhrer 2003; Sauchyn et al. 2002).

Traditional land use and new drivers

Fifty-eight percent of the Great Plains of North America occurs in the United States, 28% in Canada and 14% in Mexico. Only 25-30% of the prairie ecozone of Canada now consists of rangeland or grazing lands. Similar numbers are found in the United States (Gauthier et al. 2003). Spatial and landscape fragmentation analysis showed that within Canada, Saskatchewan has the greatest percentage of the prairie ecozone, but only 21% of this provincial prairie area is dominated by native grassland. Alberta has retained 43% and Manitoba 21% of their grassland (Gauthier et al. 2002).

The mixed grassland of the Canadian Prairie has developed under a subhumid to semiarid climate in Saskatchewan and Alberta, above the 49th and below the 52nd parallel. Conditions in this zone can be extreme. Temperatures ranging from -40°C in winter to 40°C in summer (Environment Canada 2006a) and overall conditions of moisture deficit are an important characteristic of this ecozone. Typically, soil moisture is good in the first part of the growing season due to the moisture left by snow melt and reduced evapotranspiration under cooler temperatures, but July and August are typically very dry (Figure 17.1).

Climate and soil moisture conditions of the mixed grassland ecozone have made this region suitable for the production of premium quality wheat. Wheat plants develop under condition of moisture sufficiency in the first part of the season but become stressed as soil water is being used up. Drought stress shortens the period of grain filling, prematurely interrupting carbohydrate translocation to the grain. The late season drought results in the production of grain rich in proteins, which accumulate early in the grain filling process. Years, where the drought cycle comes too early, are marked by crop

failure and farm revenue stabilization plans must support farmers until the return of more favourable times.

Sauchyn et al. (2002) have reconstructed past climatic conditions of the prairies, based on tree rings and diatom-inferred lake salinity records, and have predicted future conditions using the climate change forecasting models HadCM3, CGCM2 and CSIROMk2b. It appears that the period of 1961 to 1990, from which the climate normal is calculated, may have been the most benign climate of the past 750 years. The period from 1700 to 2000 was seemingly characterized by an average aridity index (precipitation/evapotranspiration) of 0.415, a level lower than the index of 0.627 computed over the more recent period of 1900 to 2000, and by more frequent extended periods of aridity than in the last century. Models indicate that the immediate effect of global climate change would be to revert the Canadian prairie climate to conditions similar to those of the past where aridity periods could persist over a decade or longer. Wheat-based ecosystems and the society depending on a wheat production industry may not recover from decade-long periods of crop failures.
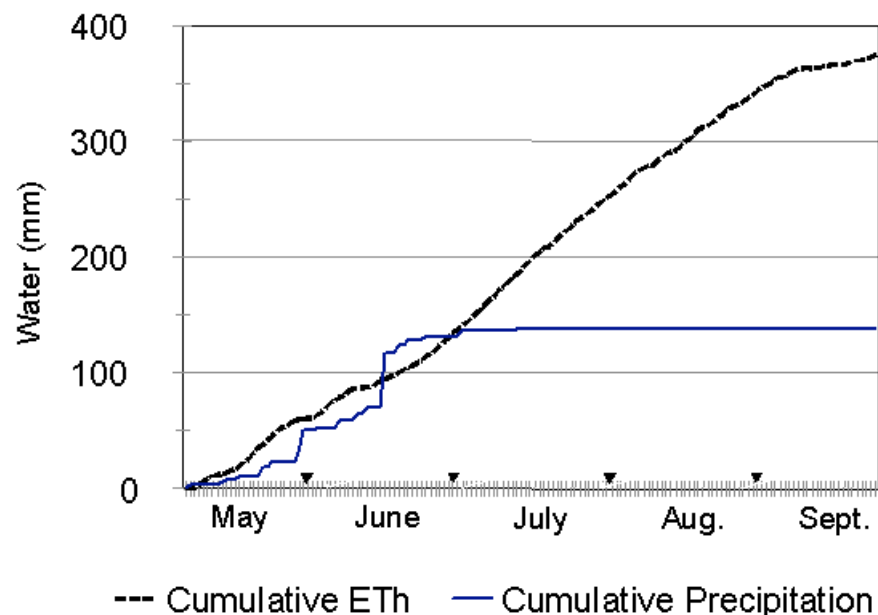

Figure 17.1. Estimated evapotranspiration and measured precipitation in Val-Marie, SK, from May 1st to September 30th 2006. Evapotranspiration was calculated with the equation of Hargreaves (Maulé et al. 2005) and data collected at the Swift Current weather station. Precipitation data are from southwest Val-Marie (Environment Canada 2006b).

Soil Biota and Soil Function in the Mixed Prairie

In contrast to wheat-based systems, ecosystems composed of species native to the mixed grassland may be able to sustain extended periods of aridity. Their organisms are adapted to the prevailing dry climate, and conditions perceived as droughty by the wheat industry

may offer some native organisms an opportunity to proliferate. Water deficit is a relative notion. In one experiment in 2003, for example, seasonal variation in the biomass of three soil microbial populations - saprotrophic fungi, arbuscular mycorrhizal fungi, and bacteria - was measured monthly in the top 0-7.5 cm of wheat growing soil (Figure 17.2).
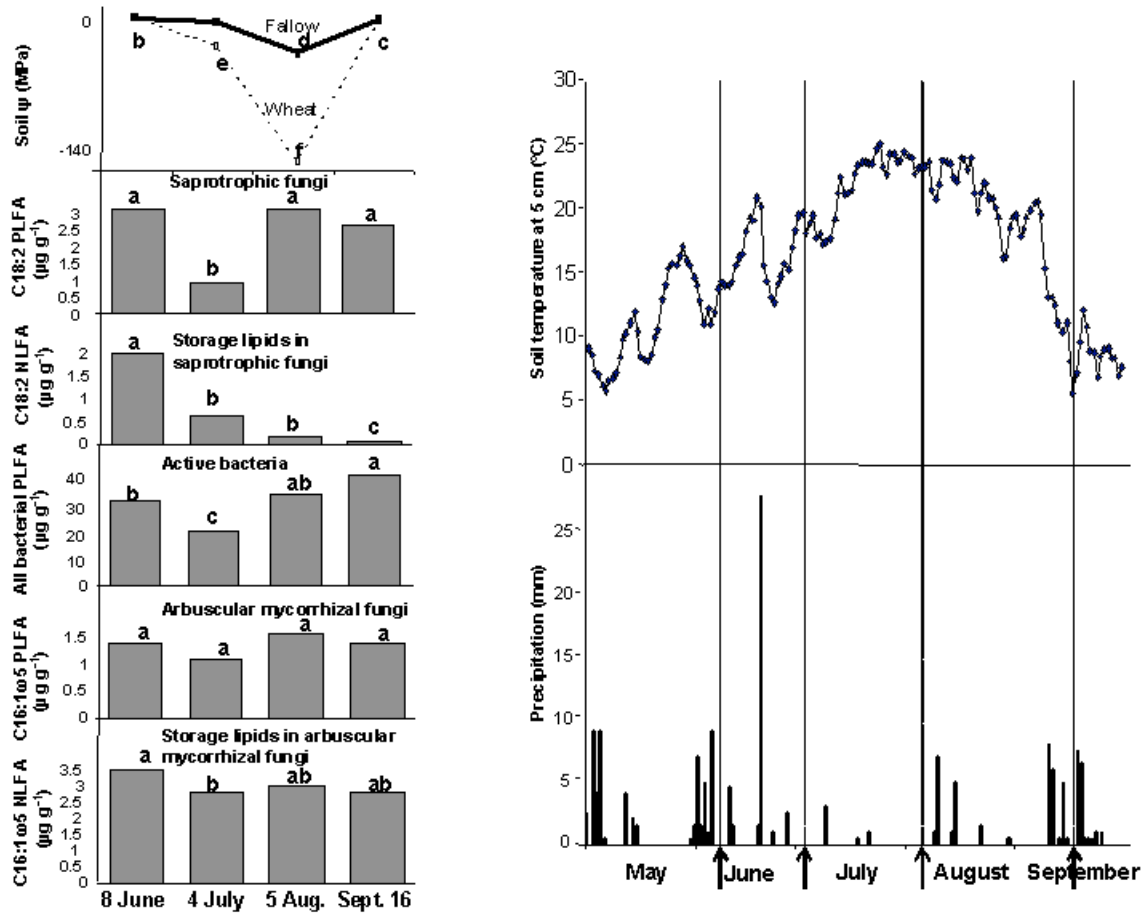
Figure 17.2. Soil water potential, along with microbial population biomasses and abundance of fungal storage lipids expressed by phospholipidic and neutral fatty acid biomarkers respectively, in the top 0-7.5 cm soil layer, under a wheat crop and bare fallow, in the summer of 2003, at the Swift Current Semiarid Prairie Agricultural Research Centre. Soil temperature and precipitation during the growing season are also presented. Arrows indicate the date at which water potential and microbial measurements were made. (From Hamel et al. 2006 Soil Biology & Biochemistry 38:2104-2116).

Biomass was lowest in July, when soil moisture level was average, and greatest in August, when soil moisture availability was extremely low. A storm event that brought 28 mm of water in less than 1 hour on June 20 was the likely explanation for the low soil microbial biomass found in July. Many microorganisms accumulate intracellular solutes or osmo-protectants that may create stress when the soil is re-wetted rapidly after drying (Kieft 1987). Therefore, a sudden rise in the soil water potential in dry soil can lyse a

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large numbers of microbial cells (Campbell et al. 1973; Hamel et al. 2006). Dew formation is enough to stimulate microbial growth in dry mixed grassland soil (Biederbeck et al. 1977). Water stress has no defined value, and can only be understood with knowledge of the adaptation range of the affected organisms.

Certain groups of organisms do well under semiarid conditions, but others do not. Fauna found in semiarid Saskatchewan soil were 490 m^{-2} Elatridae; 74,823 m^{-2} Collembola; 31,191m^{-2} Acarina; 2.7 x10^6 Nematoda; and 34,083 m^{-2} Enchytraeidae, but no earthworms (Willard 1974). These numbers are similar to those reported by others from prairie ecosystems (Stanton 1988), but generally lower than those reported from other ecosystems (Behan-Pelletier 2003; Koehler 1999; Paul and Clark 1988; Rusek and Marshall 2000; Whalen and Hamel 2004). Dry soils are not a favourable habitat for the soil fauna in particular for earthworms, which are rarely or never found in arid and semiarid grasslands (Stanton 1988) although they are abundant in irrigated gardens. In grasslands, standing microbial biomass is about equivalent to half that of net primary productivity (NPP) and mineralization is explained by the activity of bacterivorous and fungivorous protozoa and nematodes (Stanton 1988).

Compairing introduced versus native plant species, and plant mixtures versus monocultures

Work by the Semiarid Prairie Agricultural Research Centre near Swift Current and in the Grasslands National Park, Saskatchewan, detailed the impact of multiple species seeding on forage production and soil microbial dynamics and function, and of changes occurring in soil microbial populations after conversions between introduced and native grass species and seeding of monocultures versus mixtures (Schellenberg 2008, Schellenberg et al 2008). There were year to year variations in productivity (Table 17.1). Inter- and intra-species competition increases with each year as stands mature, available resources are depleted. Complete exploration of the soil zone and canopy cover development took 4 to 5 years. As the stands age water and N limitations increased. The introduced grasses produced greater biomass in the first 2 years since both function as colonizing species whereas the native species used in this study were later seral species. Mixtures may, in the future, yield more than monocultures as a result of better resource exploration, due to different rooting depth patterns found in mixtures versus monocultures.

These plots were also used to assess endophytic colonization of roots (Giovannetti and Mosse 1980). A fine, vesicle and arbuscle forming mycelium was distinguished from a coarse, coil forming mycelium (Rillig and Field 2003). Plants were abundantly colonized by non-AMF endophytes, which share root occupation with AMF. Root colonization decreased with soil depth and did not differ between plant species. The extensive colonization by these apparently non-pathogenic fungi found in roots of prairie pasture plants suggests that these fungi are an adaptation to the harsh condition of the region. However, how these unknown microbial communities contribute to plant fitness or how short term changes in the environment affect them is yet unknown. Fungal endophytes have been associated with growth stimulation (Waller et al. 2005), thermotolerance (Redman et al. 2002), and early season plant nitrogen uptake (Schardl et al. 2004). All these effects would benefit plants. These preliminary results on conditions

in these different plant stands will be used to understand the soil microbial data that is still being collected. This data includes the description of soil microbial biomass and community structure.

Table 17.1. Biomass production of native and tame grass species in pure stand and mixture, as influenced by N fertilization.

	Year			
	2001 (establishment year)	2002	2003	2004
	------------------- g m^{-2} ------------------			
Native species				
Green Needlegrass	154.1	242.3	393.0	484.8
Western Wheatgrass	167.0	393.6	383.7	562.8
Switchgrass	143.5	377.9	489.9	540.5
Native Mixture	158.0	351.7	420.0	626.8
Tame species				
Crested Wheatgrass	168.4	367.7	579.3	581.6
Russian Wildrye	124.6	387.4	448.4	543.4
Tame mixture	159.7	505.9	515.1	692.4
Standard Error	*19.9*	*47.2*	*41.2*	*69.1*
Fertilization				
Fertilized	158.0	416.8	479.8	729.3
Unfertilized	149.2	333.7	347.2	385.0
Standard Error	*10.6*	*25.2*	*20.6*	*34.6*
Contrasts	-------------------- Probabilities----------------------			
Native vs Tame	0.7570	0.0347	<0.0001	0.1303
Cool season vs Warm season	0.6531	0.5713	0.4039	0.3188
Mixture vs monoculture	0.6625	0.0650	0.0374	0.0196
Fertilized vs Non-fertilized	0.5631	0.0252	<0.0001	<0.0001

Comparing adjacent native, restored and crested wheatgrass stands

Natural selection has produced efficient ecosystems. Comparison of indicators of soil quality in native and man-made ecosystems may reveal how the sustainability of man-made ecosystems can be improved. Four sets of adjacent soils in the southwestern Saskatchewan (49° 22' N, 107° 51' W, elevation 808.0 m) under native prairie vegetation, under crested wheatgrass, and sites that had been restored and seeded into native plants (in various stages of establishment) were sampled under moist conditions in June and under drought condition in August (Figure 17.1). Plant richness, i.e. the number of different plant species, was highest at the restored sites in part due to a greater number of forbs. A characteristic of the native sites was the complete soil coverage with mosses and lichens colonizing the soil between plants. Crested wheatgrass stands had about 50% of bare soil even though these stands were established over five decades ago, reflecting the ability of crested wheatgrass root system to aggressively occupy the top soil layer and utilize available water.

Summary

Seeding multiple species mixes increased resource exploitation with the potential for more stabile yields due to a greater number of species accessing resources at different temporal and spatial scales. Comparison of data from agricultural, native and restored stands, showed greater ground cover for more complex plant populations in the droughtier part of the growing season. This in turn results in some soil moisture retention through shading. Perennial plants enter a dormant state as temperatures rise and precipitation stops. For the Canadian prairies this occurs in the July to August period with some occasional respite in September. This seasonal variation occurs within microbial populations as well. Increased soil coverage with lichens and moss will provide soil moisture conditions conducive to continued microbial activity for a longer period of time. Interactions between species, soil environment, and weather impact the plant and microbial communities resulting in varying populations. The stage of development or temporal scale also affects which species are present. The work at Swift Current and Grasslands National Park is only beginning to provide clues as to how these interactions occur.

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18.
Natural grasslands of Uruguay: Alternatives for its conservation

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The grasslands of the Rio de la Plata represent the most important biome of Uruguay and occupy approximately 70% of the total area (Table 18.1) (Domínguez and Prieto, 2002, MGAP – DIEA, 2002). In Uruguay, no record of natural plant communities prior to the introduction of livestock exists. Cattle were introduced to Uruguay from Santa Fe (Argentina) around 1610 (Domínguez and Prieto, 2002). Grassland characteristics did not change for 300 years until the middle of the 19th century, when the enclosure of fields became general. The relationship between the natural resources (water and grasslands), livestock grazing and landowners during the colonial time explains why livestock is essential to the Uruguayan economy and culture until today. Natural grassland provides the principal resource for Uruguay's main exports: meat, wool, and leather. Many ranches have a long relationship between human use and environment (Evia and Gudynas, 2000)

Uruguay's climate is temperate. Precipitation is distributed evenly throughout the year, although interannual variability is important. Soils show a great variability within the country due to geomorphologic and lithologic factors. Although agriculture and grasslands occupy most of Uruguay, 90% of its population lives in urban zones with approximately 45% in the capital Montevideo. Even among urban perceptions "nation" is associated with "livestock country". Until today, this ties unquestionably to the use of the territory (Table 18.1) and the volume of exports due to this sector, although livestock no longer explains the greater proportion of the national IBP (12% in 2004) (Caputi, 2005).

The biogeographic Uruguayense region is represented by subtropical – temperate grasslands on undulating topography. A diversity of grasses exists in association with natural forest, shrubs and marshlands (Chebataroff, 1960).

Throughout Uruguayan history, ecological, social, economical and political aspects determined the exploitation of the natural resources and were modelling the landscape. Extensive grazing with cattle and sheep is the dominant forage exploitation. The grazing and selection of the most appetizing species have modified the vegetation composition. The greater biological diversity has been demonstrated to be present in plots with controlled grazing than plots without grazing or with very intensive use of it (Chebataroff, 1960, Altesor et al, 1998). In addition, overgrazing and burning of fields are common practices that have contributed to the modification of natural plant communities and landscapes.

In addition to economic services that natural grassland sustains, the ecosystem services that it offers have great relevance, although it is difficult to assign a market value. Aspects such as carbon capture (Watson et al, 2000), the "thermal carpet" effect and conservation of soil, the preservation of vegetal biodiversity and the habitat it provides for animal species are considerable (Domínguez and Prieto, 2002; Pierri and Foladori, 2001).

Table 18.1. Land use in Uruguay (thousand of hectares)

Use	Area
Natural grasslands	12.500
Fertilized grasslands	2.400
Sown prairie	1.300
Crops	650
Planted Forest	635
Native Forest	600
Total	18.700

Land use change

Although the productive use of grassland dates back hundreds of years, land use has changed. In recent years the area occupied by planted forests (basically eucalyptus) and by soybean culture (DIEA, 2003) is creating landscape fragmentation, which has not been evaluated until now. Different visions in relation to resulting environmental impacts exist: academia is mainly polarized while the population are more in agreement with the afforestation trends.

The conversion of low productive natural grasslands to managed forest plantations results in net CO_2 fixations (Baethgen and Martino, 2000) as shown in the greenhouse gases inventory by sources (MVOTMA, 2005). Nevertheless, due to a high aerial/root biomass relation in forests relative to grasslands, final carbon capture is less than grasslands, since the aerial part is harvested and "exported " (Jackson et al, 2005). Carbon losses reported from forested areas represent about 34% of the carbon previously fixed by grassland (Facultad de Ciencias, 2005). Clearly, a more detailed carbon balance in different productive situations and in forest production systems is needed (Baethgen et al, 2001). Greater water losses by evapotranspiration and greater interception of rainwater by forests (Facultad de Ciencias, 2005) is one of the most controversial negative impacts, and experiments comparing and quantifying hydrological differences between systems are still being carried out (Facultad de Agronomía, 2006).

There is agreement on the loss of biodiversity associated with the substitution of grassland by tree plantations (Baethgen and Martino, 2000; Laterra and Rivas, 2005; Facultad de Ciencias, 2005). This important threat to the biodiversity and ecosystem services that natural grassland offers, depends mainly on socio-economic forces that regulates the land use (Laterra and Rivas, 2005).

Forest production occupies more workers than other occupations at national level (DIEA, 2003), and provides arguments in favour of this land use change, both in political speeches and in the academic sector (Martino, 2000). However, it is important to quantify social impacts and the quality of life of the workers and their families around the forest plantations.

In 2004 alone the surface seeded with summer crops increased by 36%, due entirely to the expansion of soybean. The predominance of soybean now causes concern about the sustainability of the continuous agriculture model (MVOTMA, 2005), losses of biodiversity and soil erosion. Zero tillage and the associated technological package (use

of glyphosate) also raises concerns about the loss of native species and possible weed invasions, in some cases exotic and resistant to herbicides.

Climate variability and climate change

Downscaling of the HadCM3 General Circulation Model for Uruguay indicates an increase in temperature up to 2.5ºC or 1.6ºC for 2050 for the A2 and B2 socio-economic scenarios respectively. Precipitation changes reach +0.2 mm/day for scenario A2 and up to +0.1 mm/day for B2 (Caffera et al, 2005).

Consequences of warming trends were evaluated in the region for soybean, maize, wheat and sown prairie using crop modelling (Giménez et al, 2005). Results indicate that sown grasses would be less affected than crops. Results by Caffera et al (2005) and preliminary results of the IAI Seed Grant Project (Cruz et al, 2007) both show that historical temperature and precipitation variability was greater than the predicted climate changes over the next 50 years. At the moment it is still not possible to simulate variability for the future, but if it is assumed that the future climate variability is at least as large as in the past, it would be appropriate to focus on variability rather than trends to prevent or alleviate the possible effects of climate change. Being prepared to climate variability increases the chances to be prepared for climate change.

Grassland Conservation

Conservation should be in situ because biological diversity would be conserved in its habitat maintaining the interrelations between the organisms and their environment (Laterra y Rivas, 2005, Domínguez and Prieto, 2002). The conservation of the biodiversity of grassland ecosystems should include large herbivores as management factor to sustain biological diversity (Chebataroff, 1960; Altesor et al, 1998; Laterra and Rivas, 2005). Planning and designing protected areas should include georeferenced ecogeographical monitoring (Laterra and Rivas, 2005). It is important to use indicators for resilience, like primary productivity, botanical composition and the standardized green index, NDVI. It is necessary to explore and to map the heterogeneity of the natural grasslands at the plant community level. Usually the heterogeneity of natural grasslands was related to soil and geological substrate, but fitosociological studies of these communities are missing. Climate variability must be included in research on grassland evolution. Extreme events have had negative impacts at all level on Uruguayan grass and livestock production systems along history.

Education curricula should include subjects related to environmental change, incorporating the historical perspective of co-evolution of environment and people (Crumbley, 1994). The translation and communication of messages from the academic sector towards the decision makers (at political level or at the rural sector) is as important as the generation of the knowledge itself. In this sense, the effective transference must contemplate aspects such as language, media and the idiosyncrasy of rural communities. In addition, common knowledge and needs of farmers and politicians should be incorporated in the academic research.

It is clear in a country like Uruguay, whose national identity is related to livestock, basic aspects of the structure and functioning of this ecosystem should be addressed early in the education programs, contributing to the valuation of the grassland ecosystem and appreciating not only its productive function.

The speed of land use changes in Uruguay and the perspective of climatic change, deserve a social dialogue without delay. It is known that some degradation of the environment is irreversible. The point of no return is in most cases still unknown. It is necessary that people understand the gap between political time scales and ecological ones and the inertias associated with both. This dialogue should result in the appropriation by all individuals of their social and ecological destiny (Acot, 2005). The message may be simple: it is always possible to do things another way.

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