Working Document No. 167
September 1997

INTEGRATED CONCEPTUAL FRAMEWORK FOR TROPICAL AGROECOSYSTEM RESEARCH BASED ON COMPLEX SYSTEMS THEORIES
A CIAT/University of Guelph Project

PROCEEDINGS OF THE FIRST INTERNATIONAL WORKSHOP (Held at CIAT, 26-28 May, 1997)

Edited by Tamsyn Murray and Gilberto C. Gallopín

CIAT
Centro Internacional de Agricultura Tropical
International Center for Tropical Agriculture

Introduction

This workshop is the second in the series of workshops held by the CIAT-University of Guelph project. In the first workshop, held on March 5 1997, we presented the Project and discussed the main issues considered relevant to those working in the Ucayali region. Workshop participants comprised CIAT scientists with future and ongoing research projects in Ucayali.

This second workshop, "First International Workshop of the CIAT-University of Guelph Project" involved scientists representing very different areas of expertise. The first group consisted of researchers from Europe and Canada who are currently working in the area of complex systems theory (CST). They were invited to help enrich the conceptual developments currently in progress. The second group comprised Peruvian scientists who were able to provide us with detailed knowledge and data of the case study, Ucayali. These experts were selected based on their abilities to discuss the dynamics of the main resource use activities in the region; fisheries, forestry, coca, agroforestry, and cattle and forages. Lastly we included all CIAT scientists involved in research projects in Ucayali.

In bringing together the CST theoreticians and the more grounded practitioners working on site, we hoped to benefit from the combining of theory and practice, abstract and concrete. We wished to apply the theories to the case study and with the help of the local experts modify and develop them. In addition the practitioners may see their work in a larger context and learn from the theoretical insights of the CST experts.

Since this project strongly emphasizes the need and importance of stakeholder involvement in all aspects of the research conducted, the workshop played an important role in the process of establishing collaborative ties with community members. We wish to maintain and enhance these relationships, thus allowing us the opportunity to be guided by their expertise and knowledge.

The proceedings comprise all the presentations given by the CST experts, Peruvian experts and CIAT scientists. It also includes the comments, recommendations and further developments of the conceptual ideas that took place in the workshop discussions.

Lastly, it is important to draw attention to the fact that the presentations and workshop discussions necessarily represent the opinions of the chosen mix of people and therefore any interpretation of the conclusions must be viewed within this light. In addition the conceptual models proposed here are in a working form, and will necessarily continue to be adapted and modified until the project is complete.

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Erik Veneklaas, Land Management

Manuel Winograd, Land Management

Workshop Agenda

Day 1: Monday May 26

Introduction (08:00-08:40)

1. Welcome

2. Introduction of the Participants

3. Gilberto C. Gallopín: Introduction of the Project

   Overview of the goals and objectives of the Project; Project history; Project team etc.

   See Document I: Overview of the Project

Session I: Overview of Pucallpa (08:40- 12:00)

This session will involve short presentations from the workshop participants from Peru as well as CIAT scientists working in Pucallpa. The goal is to provide those unfamiliar with the case study a detailed and rich description of the region from different perspectives.

See Document II: Overview and Synthesis of Pucallpa/Ucayali

Speakers:

1. Ernesto Raez-Luna, Land Managment, CIAT, Cali (20 mins)
   "Historical Overview"

2. Humberto Guerra Flores: Instituto de Investigaciones de la Amazonia Peruana (IIAP), Iquitos (20 mins)
   "The State of the Fisheries of the Peruvian Amazon"

3. Eduardo Musso, IICA & GTZ, Lima (20 mins)
   "Drugs, producers and decision-making"

4. Miguel Ara: Director of Use and Management of Natural Resources, CODESU, Pucallpa (20 mins)
   "The Forestry industry in Ucayali"

   Break: 10:00-10:20

5. Ricardo Labarta: International Centre for Research on Agroforestry (ICRAF), Pucallpa, Peru (20 mins)
   "The Use of Natural Resources in the Amazon Region of Pucallpa"

6. Erik Veneklaas: Land Management, CIAT, Cali (20 mins)
   "Key Ecological Processes in Ucayali"

7. Federico Holmann: Tropical Forages, CIAT, Cali (20 mins)
"Dual Purpose Cattle Production in Pucallpa – Tropileche"

8. Sam Fujisaka: Land Management, CIAT, Cali (20 mins)
"Land Use Characterization in Ucayali"

Discussion: Questions and clarifications (45 mins)

Session IIa: Complex Systems Tutorial: Dr. James Kay and David Waltner-Toews (13:30pm – 16:30pm)

This session will provide a thorough explanation of the basic concepts, approach and research methods of complex systems theories (CST). It is intended to provide those unfamiliar with CST with a good understanding of the theories which the Project aims to apply to the Pucallpa case study. This session is open to all CIAT staff.

Break: 15:00 – 15:20

Day 2: Tuesday May 27

Session IIb: Panel Discussion: Responses to Complex System Tutorial (8.00 - 9:45)

This session includes presentations from other scientists working in complex systems. They will highlight different perspectives and approaches to understanding complex systems. Each presenter will outline their research approach in the context of the seminar on CST given on the previous day. It is intended that the other participants gain an understanding of different views of CST as well as helping to develop a common language for all participants.

Participants of the Panel:

1. Mario Giampietro: Senior Researcher, Istituto Nazionale della Nutrizione. Rome, Italy (10 mins)

2. Henry Regier: Toronto, Canada (10 mins)

3. Gilberto Gallopin: Land Management, CIAT, Cali (10 mins)

4. David Waltner-Toews, Population Medicine, University of Guelph, Ontario, Canada (10 mins)

Discussion: Questions and clarifications (55 mins)

Break: 09:45-10:05

Session III: Research Process and System Description (10.05 - 12.00)

This session explains the research process taken by the Project and in this context identifies which are the subsequent stages that will be addressed in the workshop. The system variables and the general causal structure of the system will be discussed. Following this different categories of the CST concepts will be clarified.

1. Tamsyn Murray: The Research Process (20 mins)

2. Discussion (30 mins)

3. Identification of basic categories of complex system concepts (whole group) (45 mins)

4. Gilberto C. Gallopin: Perceived Goals and Indicators (20 mins)

Session IV: Re-Examination of the System using Complex Systems Theories (13:30 – 16:30)

In this session we wish to develop a CST interpretation of the case study using the basic concepts already explained in the seminar and further refined in Session III. The goal is to construct a conceptual "model" (not in the quantitative sense) of Pucallpa/Ucayali with CST and identify the most critical guiding questions, hypotheses and metaphors that will help us better understand the key processes and dynamics of the system.

Break: 15:00-15:20

Day 3: May 28

Session V: Development of a Conceptual Framework

Based on the previous description of the case in complex system terms, we wish to at least initially outline the skeleton of a framework, that can then be further refined and tested in Pucallpa. This framework is intended to provide a guide for agricultural research in messy complex situations such as those that present themselves in the region.

Break: 10:00-10:20

Session VI: Recommendations for Research Priorities

With the new insights derived from the application of CST, we wish to identify research priorities for CIAT for the region. At present CIAT has 7 projects working in Pucallpa. The integrated conceptual framework should help in locating each project in a similar context and help identify synergistic and complementary relationships that can be exploited. We wish to clarify how data and results from one project can feed into others and how as a whole they can contribute to a more complete picture of the situation.

Break: 15:00 – 15:20

INTRODUCTION OF THE PROJECT

Gilberto C. Gallopín, Land Management, CIAT

Thank you for your participation in the First International Workshop of the CIAT/UG project.

The **purpose** of this workshop is manifold:

1. To get together practitioners and theoreticians working on agricultural and natural resources research and management.

2. To discuss and illustrate the application of ideas arising from Complex Systems Theories (CST) to a case study in a focused manner and to share them with the agricultural research community.

3. To critique and extend the preliminary conceptual framework generated by the Project and our understanding of both general and site-specific processes operating in Ucayali, Peru.

3. To perform a collective exercise of re-examination of the Ucayali system.

The **expected outputs** of the Workshop are:

- An improved conceptual framework for agroecosystem research.

- A proposed CST characterization of Ucayali.

- A set or research priorities for the Project.

After the formal Workshop is over (Wednesday May 28), there will be two days dedicated to informal discussion between the researchers working on CST in order to go into deeper analysis, critique, and recommendations regarding the application of CST.

Personally, I see this Workshop both as a test of the practical usefulness of CST to agroecosystem research, and as a challenge to CIAT (and perhaps the CGIAR) to incorporate emerging insights coming from the study of complex systems of many kinds.

History of the CIAT/UG project

The origins of the project can be traced to June 1994, when Dr. David Waltner-Toews and myself met in a Workshop on Agroecosystem Health held in Ottawa. We quickly discovered we had common interests, particularly about looking for new ways of addressing agroecosystem sustainability and health. David was at that time starting a Canadian-wide project on Agroecosystem Health, and we realized that potential for cooperation was high. The similarities and differences between temperate and tropical agroecosystems have been discussed at that workshop, and we perceived the importance of including tropical agroecosystems in the analysis.

On the other hand, I had been involved in efforts to put together an international group of scientists working on different aspects of complex systems and sharing a common interest to explore the implications of complex systems theories for practical policy- and decision-making for sustainable development. David was a member of this informal group.

While we met in different occasions for workshops and discussions, the first opportunity for serious cooperation arose when we learned about the new CGIAR-CANADA Linkage Fund (CCLF) set up by

CIDA. We made a proposal for the fund in 1996, and it was approved in the same year.

Project support and execution:

Supported by the CIDA CGIAR-CANADA Linkage Fund and executed by CIAT and the University of Guelph

Project Team:

Overall coordination: Dr. Gilberto C. Gallopín (CIAT).

Scientific coordinators and Principal Investigators of the project: David Waltner-Toews (University of Guelph) and Gilberto C. Gallopín (CIAT).

Scientific Advisor: Dr. James Kay (University of Guelph)

Senior Scientist: Manuel Winograd
Research Associate: Tamsyn Rowley
Research Associate: Ernesto Raez-Luna
Analyst: Hebert Montegranario

Other staff from CIAT and the University of Guelph participating contributing original data, specialized scientific advice, and critiques of the ongoing research:

CIAT:

Dr. Sam Fujisaka
Dr. Erik Veneklaas
Dr. Peter Jones
Other scientists (to be defined)
Scientists working in the selected sites (to be defined by the project)

University of Guelph:

Dr. Sally Humphries
Dr. Clarence Swanton

Project duration: three years

Project Rationale:

The problematic social, economic, environmental and productive issues facing agriculture and agricultural communities are part of a complex set of activities involving farmers, farm organizations, rural communities, and national, regional and international governments and institutions.

Environmental, social, and economic impacts have repercussions not only for individual farmers where they live, but for all actors at all hierarchical levels in the agroecosystem.

Constraints and opportunities occur at each level in this hierarchy; e.g., the nature and variety of markets, soil types and erosion, social structures and national policies.

Among many researchers and development experts there is an increasing sense of un-ease with traditional sectoral and disciplinary approaches, and a consensus that it is important to take a broad view when trying to solve agricultural problems.

It is increasingly obvious that the quest for sustainable agricultural development requires:

- *integration of* economic, social, cultural, political, and ecological factors
- *articulation* of the top-down approaches to development with the bottom-up or grassroots initiatives
- the simultaneous consideration of *the local and the global* dimensions and of the way they interact
- *broadening the space and time horizons* to accommodate the need for intergenerational as well as intragenerational equity.

The Technical Advisory Group (TAC) of the CGIAR has recognized the need for a new agricultural research model: "as yet, there is no accepted research model which embraces the physical, biological and human dimensions of long term (agricultural) sustainability. Developing such a model is a goal of truly international importance" (CGIAR. 1993. "The Ecoregional Approach to Research in the CGIAR". Report of the TAC/Centre Directors Working Group. CGIAR Mid-Term Meeting, Puerto Rico, May 1993, page 8.)

A *research model for sustainable agriculture* will certainly be more flexible and in some aspects at least, less easy to quantify than a research model for physics or chemistry. The CGIAR was referring to a new, interdisciplinary, multi-level, both site-specific and contextually meaningful, systemic approach to agricultural research, as opposed to the dominating "commodity model".

A research model in this sense includes essentially:

- a goal (sustainable agricultural production and development),
- a conceptual framework,
- a set of procedures,
- falsification criteria.

The development of a *holistic conceptual framework* for understanding and anticipating agroecosystem dynamics and behavior is an essential piece of a new research model.

Project Objectives

- To develop a conceptual framework for the holistic understanding of agroecosystems as hierarchical systems, using the new ideas being derived from Complex Systems theories.

- To apply this framework to concrete tropical agroecosystems in order to assess its applicability and usefulness for guiding research on agroecosystem sustainability.

- To perform comparative analysis of tropical and temperate agroecosystems in terms of systemic properties (on the basis of ongoing research on Canadian agroecosystem at the University of Guelph).

- Based on the research findings, to develop teaching materials on complex systems approaches to the study and sustainable care of agroecosystems. We expect that these materials will be used in Latin America, Canada and elsewhere.

- To train young scientists in the application of concepts and methodologies derived from complex systems theories to the study and evaluation of agroecosystems.

Relevance of Complex Systems

The rapidly developing field of complex systems theories is helping provide new insights on the properties and behavior of systems that are characterized by a high degree of complexity, a complexity that is characteristic of any socio-ecological system such as agroecosystems. Those new insights generate new relevant questions for research, and are beginning to provide new answers.

Complex systems are differentiated from simple systems, but also from what some call complicated systems. In very basic terms, the distinction between them can be stated as in Box 1.

Box 1
A TAXONOMY OF SYSTEMS

SIMPLE. Can be adequately captured by using a single perspective or description and by a standard (often linear) model providing a solution through routine operations; e.g. idealized planetary motion.

COMPLICATED. Can be characterized by a single perspective; however, it is not satisfactorily captured by a standard model. Nevertheless, it is possible to get as close as desired to a "solution"; e.g., the three body problem

COMPLEX. In any complex system, there is no guarantee of a unique "solution", or indeed any. There are (at least) two classes of complexity; except for borderline cases, most complex systems exhibit both:

> **Epistemological complexity**: it requires a plurality of perspectives. Either complementary (e.g., light, quanta, policy) and/or hierarchical (organisms, organizations, within a broader system)
> **Functional complexity**: self-organization, emergent properties; e.g., Bérnard cells.

Source: modified from http://inn.ingrm.it/compsys/manife.htm

Complex systems are characterized by the fact that *multiple* (and irreducible) *perspectives* are required in order to understand them; looking at them from only a single perspective fails to provide an understanding leading to successful resolution of problems. In the case of agroecosystems, including soil, water, plants, animals, and people, the fact that different social actors have different goals and perceptions is an essential feature contributing to the dynamics and behavior of the system. This implies that the inclusion of those features is important not only in terms of democracy and as part of the search for governance and technology transfer, but also as an epistemological necessity.

Other common property of complex systems is their hierarchical structure, including the operation of different levels of organization defining the division of the system into subsystems, of those into sub-subsystems, etc. In complex systems, this hierarchy constitutes what is sometimes called a "holarchy", a term used to emphasize that subsystems are holons, with holistic properties by themselves.

Complex systems exhibit the properties of self-organization, thereby changing their own structure and behavior in response to either internal changes or changes in their environment, and they may exhibit emergent properties, not predictable from a knowledge of the behavior and structure of their components. Those and other factors generate irreducible uncertainties about aspects of the behavior of complex systems, uncertainties that must be dealt with and that cannot be eliminated by gathering more data. Obviously, this has deep implications for agroecosystem management.

It has been shown by Prigogine and others that complex systems in interaction with their environment may exhibit deep structural changes (reorganizations) either to a "higher" or a "lower" regime. I have coined the term "anastrophic" to describe the sudden shift into a "higher" (i.e. more desirable, more complex, better able to cope) organization, while a similar change to a "lower" level is usually qualified as catastrophic. In many instances, this is preceded by increasing fluctuations of the state of the system and increasing entropy. If this kind of phenomena can be shown to exist in agroecosystems, then this feature could provide an early warning signaling the onset of a structural change (Figure 1).

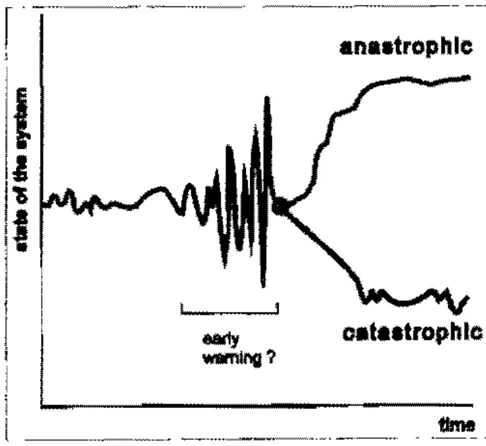


Figure 1

Complex systems may be categorized as in Box 2.

One common characteristic of complex systems is that they have more than one stable state or condition to which the system will tend to go. If a system has only one stable state it is called globally stable; in that case, if the system is moved away from the stable state, it will tend to return to it, no matter how far away or in what direction it has been displaced. This means that all perturbations are reversible; the only concern is how long will the system take to go back to its equilibrium. Only simple systems can be globally stable.

Box 2
TYPES OF COMPLEX SYSTEMS

COMPLEX PASSIVE. Changes in the system organization are basically determined by its environment.

COMPLEX ADAPTIVE. The system is able to change its "behavior" (changing the values of its variables) and "physiology" (moving between domains of attraction) to survive in a changing environment.

COMPLEX SELF-RENEWABLE. The system is able to cope with drastic change and structural collapse by regenerating itself with the same structure.

COMPLEX EVOLUTIONARY. The system is capable of changing its own structure leading to improvements in the system's performance in a changing environment. Structural changes may be progressive or punctuated; externally or internally driven.

COMPLEX SELF-AWARE. The system is able to observe itself and its own evolution thereby opening new repertoires of responses and connections. Among these are empathy , imagination and perspective of the other; and the ability to modulate responses exploring new situations and alternative visions without loss of identity.

Source: http://inn.ingrm.it/compsys/manife.htm

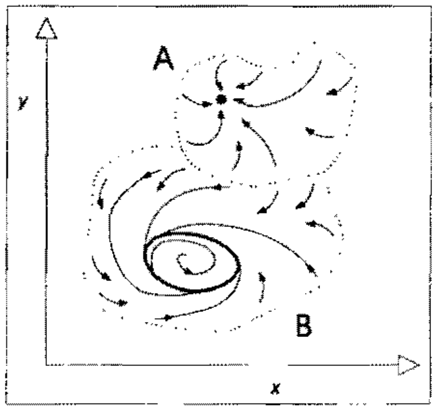


Figure 2

If a system has more than one stable state (or set of states) then it is no longer guaranteed that it will come back to the original stable state if displaced away from it; it might go to another stable state, depending not only on the size of the perturbation but more importantly on how near the system state is to the boundary separating the "basin of attraction" of each stable state. This can be illustrated graphically for the case of a system whose state is defined by the values of only two variables, *x* and *y* (Figure 2). A state of the system at a given point in time is completely defined by a point in the two-dimensional space (*x*, *y*). The case shown in the figure represents a system with two stable sets: one is a stable state (a point) and the other is a stable orbit (representing a periodic oscillation in the values of *x* and *y*). If the state of the system is originally within the domain of attraction of the stable state (or the stable orbit) it will tend to go to the corresponding state (or orbit). However, if the system is perturbed in such a way that its state crosses the boundary separating the two domains of attraction, it may "fall" into the other domain, and exhibit a sudden, qualitative, change in its mode of behavior. The system is not globally stable. This is the basis of the notion of **resilience**, which refers to the capacity of the system to remain in its original domain of attraction in the face of perturbations. Note that we are not talking here about structural changes of the system discussed before, but of changes in the behavior of a system within the same structure. It has been shown in a number of empirical cases and also through modeling, that many natural resource systems have the property of having more than one stable state or set of states. The implications for management are very deep.

Choice of Pucallpa/Ucayali as case-study

The Ucayali region of the Peruvian Amazon has been chosen as the first case-study for the development and testing of the conceptual framework because of the following reasons:

1. The case is certainly complex enough to require an integrated framework. The process of development

in Ucayali involves economic, social, ecological, agricultural, and technological dimensions.

2. A number of projects are already going on. This includes CIAT's projects as well as projects developed by other international, national, and local institutions. The project will benefit from the information and data gathered by those other projects; conversely, the project could help the integrations of those activities.

3. Research in the region is in an active state; new research and development activities are being planned. This means that some of the critical research questions identified by the project might be answered through those activities. The project may also help to set research priorities for the area.

Pucallpa land-use model

The goal of the project is to develop an integrated conceptual framework including the major factors and dimensions determining the behavior of the agroecosystem (including both human and non-human elements). Some of these factors (such as land erosion, agricultural yields, population growth) are amenable to quantification, but other factors of no lesser importance, cannot be quantified (or are trivialized if quantification is forced on them). This includes many cultural, social and political factors. Moreover, the laws or rules giving rise to many of those factors are unknown. Still, insofar as these factors are considered important in determining the behavior of the system, they must be included in the conceptual framework.

For the subsets of factors that can be quantified, the use of simulation models may be very effective in developing understanding and exploring alternative hypothesis. In a very basic sense, a simulation model is an articulated set of hypothesis under the form of variables and relations between variables, usually unfolding in time. The project is developing a dynamic mathematical simulation model of land use in the Pucallpa area, which is still at the exploratory stage. A flow diagram of the first cut model is shown in Figure 3. Despite its preliminary nature, the process of building the model has already helped to identify critical gaps in knowledge, gaps that must be filled in order to anticipate the future trajectories of land use in the region.

The model is run in the M environment, a modeling and visual interface developed by the National Institute of Public Health and Environmental Protection (RIVM) of the Netherlands. M is available freely to CIAT as a consequence of previous cooperation agreements, and it runs under Unix and under Windows 95 and NT. A sample output of the model appears in Figure 4.

Connection to the Resilience Network

The Pucallpa case study is also linked to an international research project called the Resilience Network, a joint innovative research project by the Beijer International Institute for Ecological Economics and the University of Florida, through my participation as a member of the Network. The Pucallpa case has been accepted as a case study of the Resilience Network; this will add new dimensions to the project.

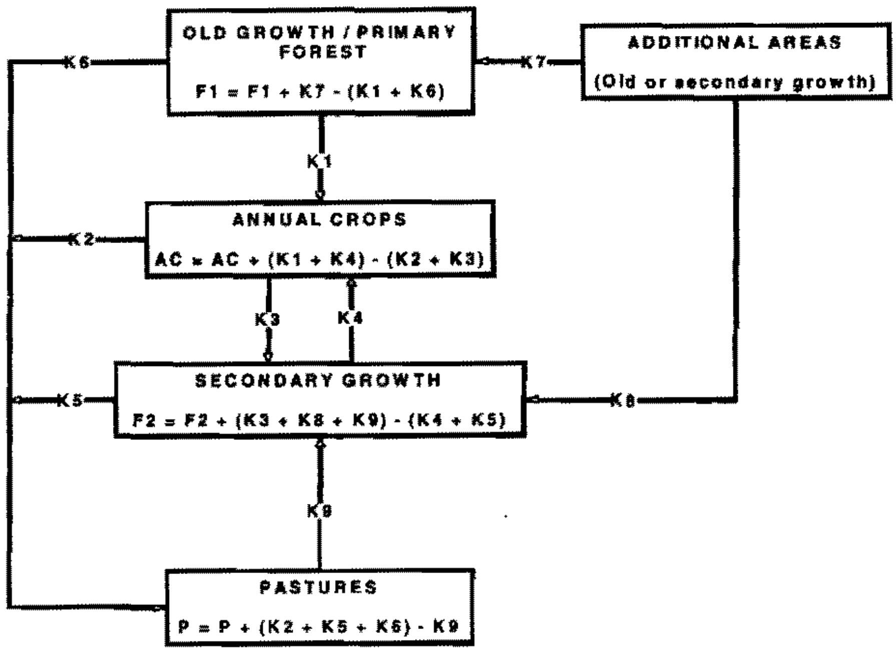


Figure 3. Flow diagram of land use in a farm (Pucallpa)

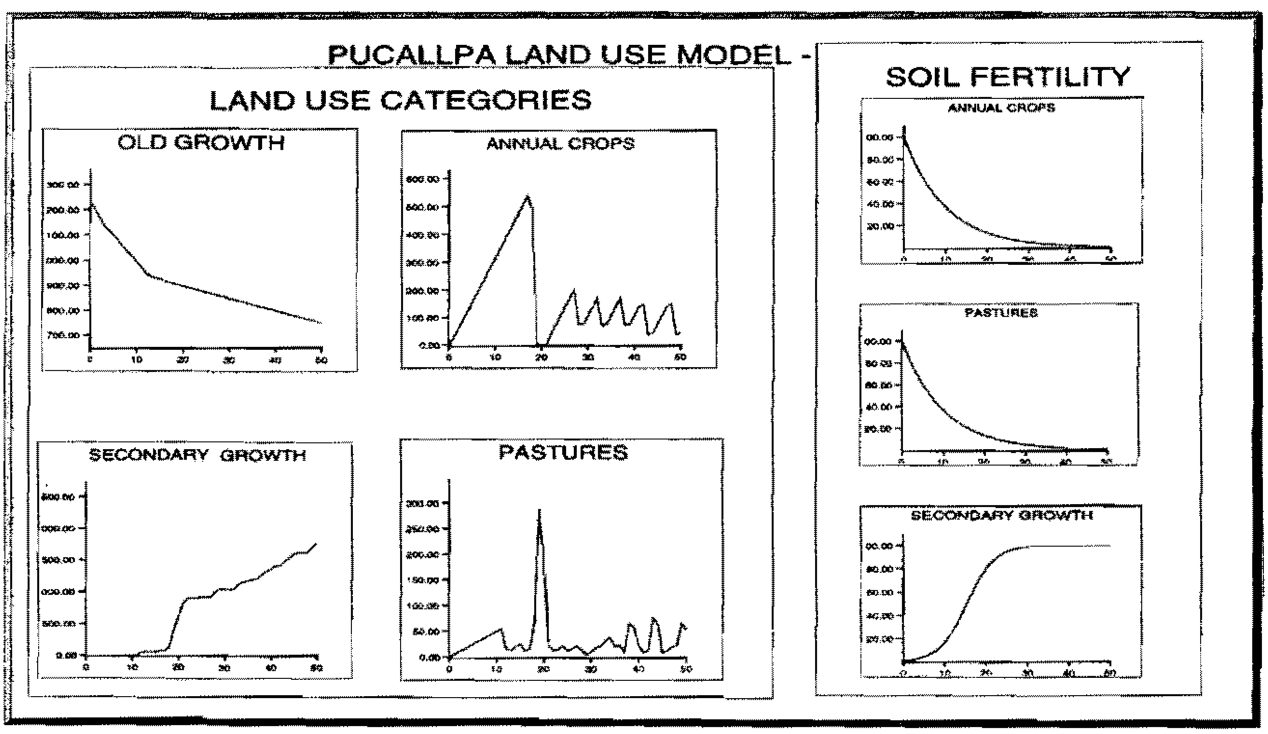


Figure 4. A simulation run of the model

In terms of resilience, the Ucayali case is intriguing. The condition of the socio-ecological system or total agroecosystem can be characterized as one of unsustainable socio-economic stagnation feeding on a huge stock of natural capital and acting opportunistically upon economic openings that may arise (economic booms, coca demand, subsidies, etc.).

If the system were confined, it would show its unsustainability very soon, but because of the vast amounts of forest and land at its disposal, it is able to destroy resources and move further away. Seen in a historical perspective, the system seems to exhibit what may be called a form of "perverse resilience", maintaining or recuperating its condition of stagnation after historical booms (and some downs), as illustrated in Figure 5. Despite being a frontier area with constant influx of people, in the last 50 years the regional economic production did not exceed 0.9% of the national, out of proportion with its resources and population. And average quality of life is apparently decreasing.

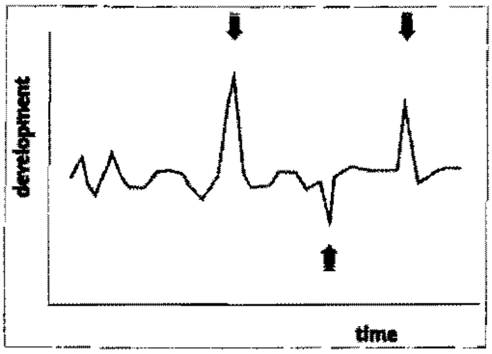


Figure 5

The system could go on indefinitely under those perturbations until natural resources become scarce.

The state space representation of the dynamics of the system is illustrated in Figure 6. The thick solid line represents the historical trajectory, with the level of development increasing initially (and natural resources decreasing). As discussed before, the level of development seems rather constant (stagnation) and it recovers after perturbations (thin lines). The level of resources, however, keeps decreasing. It is likely that when resources start to be scarce (a situation that may take 20-30 years to occur under present trends) the system will fall from the current low-development/high resources situation to a low-low attractor, as indicated by the dotted line.

The possible existence of a high-development/medium resource attractor is represented by the question mark in the upper part of the figure.

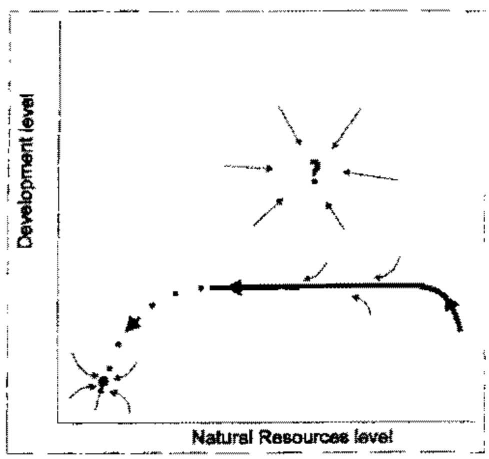


Figure 6

An alternative representation of the fall into the low-low attractor in given in Figure 7, in terms of a changing stability landscape. Here the stability landscape itself changes with the parameter NRc (or the relative size of NO and NRc).

It should be noted that under the new economic globalization and opening of the economies, the behavior of the system may be subjected to different kinds of perturbations and lose its resilience (for better or for worse).

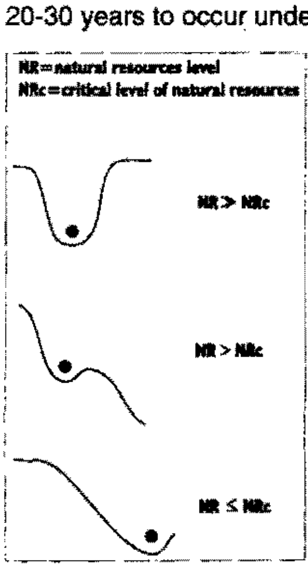


Figure 7

Highlights of the Ucayali case

In summary, and according to our present understanding (which is still preliminary) the following characteristics encapsulates the main aspects of the Ucayali case:

- Tropical agricultural frontier area with external incentives for colonization

• Continued immigration, non-rooted social structure, no historical identity

• Stagnant economy, historically resilient to perturbations (different policies, "booms" of products, violence waves)

• Locally unsustainable use of natural resources, "destroy and move" mode, feeding on huge accumulated natural capital (which could last 20-30 years)

• Organizing principles (shaping forces) of land use/occupation:

  - river system
  - road system

AN OVERVIEW OF THE PUCALLPA-UCAYALI REGION, PERU

Case Study Site

Ernesto F. Ráez-Luna and Tamsyn Rowley

May, 1997

CIDA-funded Special Project "Development and Application of an Integrated Conceptual Framework for Tropical Agroecosystem Research based on Complex Systems Theories" // PE-4 (formerly P22): "Sustainability and Land Use Dynamics in Latin America" Project.

This section provides a summary introduction to the project's case study site. Basic descriptive data related to sustainability and agriculture in Pucallpa-Ucayali are presented here in the form of a slide show.

PLAN OF THE OVERVIEW

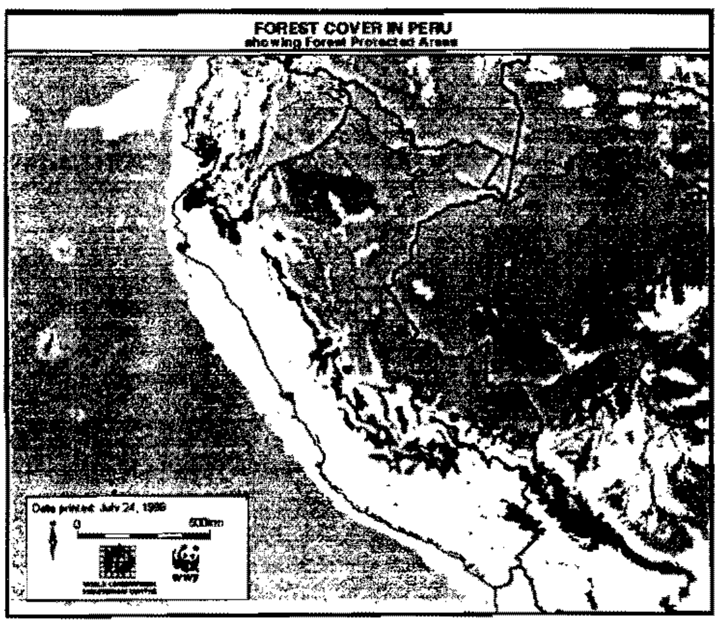
- Context
- Description
- Social Actors
- R&D Background
- Summary Diagnostics

The following slides offer a geographic CONTEXT for the study site.

Perú

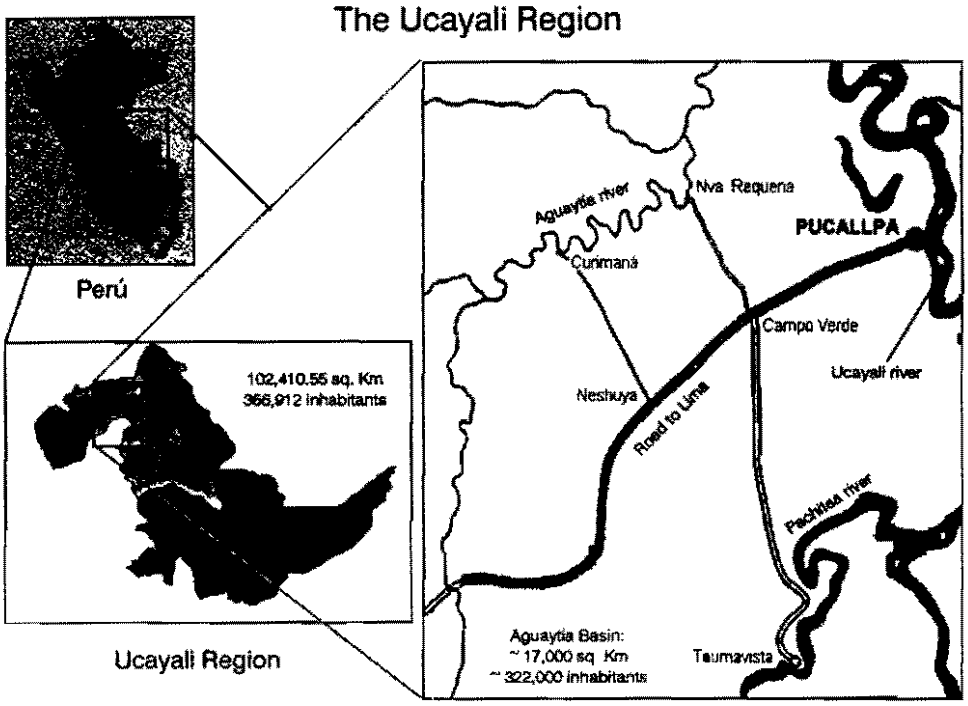
Source: Magellan Geographix

Peruvian Amazonia



Source: World Conservation Monitoring Centre / World Wide Fund for Nature, 1996.

The Ucayali Region



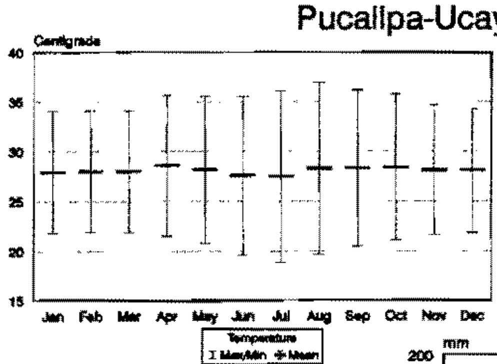
The following slides offer an ecological and economic DESCRIPTION of the study site.

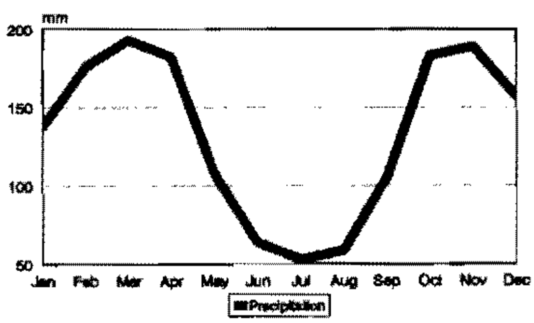
Natural Landscape

- Lowland neotropical rainforest
  - Meandering rivers, oxbow lakes, swamps.
  - Floodplains: Along Ucayali river and tributaries. Entisols.
  - "Restingas" (occasionally flooded terrain). Mixed soils, entisols.
  - Upland terraces: <u>Most of the study area</u>. Ultisols.

Source: Veneklaas 1997.

Pucallpa-Ucayali Climate





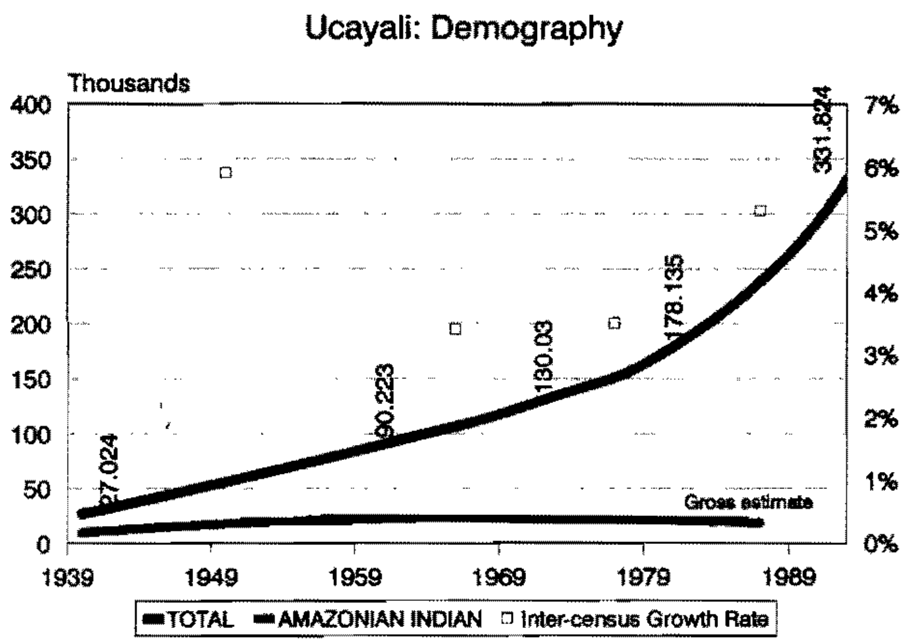
Source: Temperature: IVITA (1976-1981 averages). Precipitation: CIAT (25-year averages).

Biodiversity

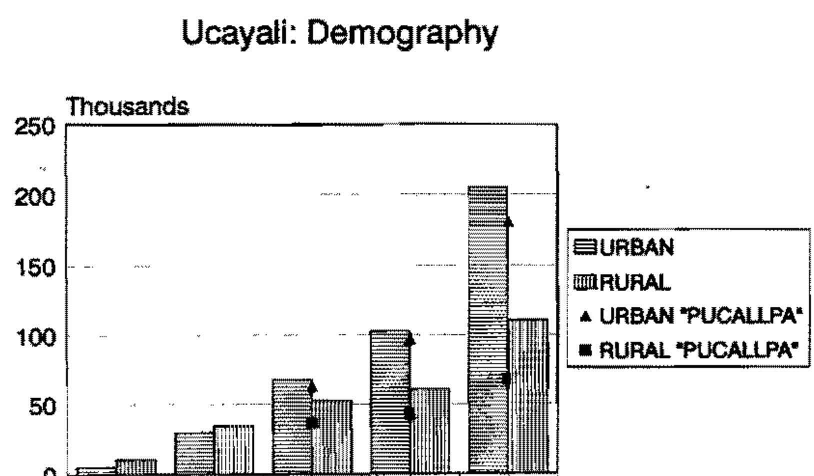
- Not assessed. Thought to be very high:
  - Perú contains 23% of the known Neotropical plant diversity (9% worldwide), concentrated in the Amazon lowlands.
  - Perú contains 44% of the known Neotropical bird diversity (18% worldwide).
  - The study area lies nearby three claimed Pleistocene refuges.
- E and S of Pucallpa considered of highest conservation priority based on species richness and endemism (CI 1991)

Summary History of Ucayali

- Since ~5,000 YBP: Amazonian cultures. Hunting-gathering and low-intensity shifting agriculture. Occasional contacts with Andean civilizations and Spanish conquerors.
- 1880s - 1930s: Rubber boom. Foundation of Pucallpa (1888).
- 1940s: Road Lima-Pucallpa (1943). Spontaneous colonization from the highlands.
- 1950s: Timber extraction stimulates colonist encroachment. Improvement of road to Lima. Major colonization waves by the end of the period.
- 1960s - 1970s: Agro-silvan economy develops. Subsidy from nature. Cattle numbers increase.
  - 1965 - 1975: Peruvian Amazon: Fur and live animal trade.
  - 1970 - 1972: Peru: Nationalist military government re-distributes land.
- 1980s: Coca boom. Nation-level economic crisis (hyperinflation) and terrorist guerrillas. Generalized abandonment of lands (cattle numbers decrease).
- 1990s: Control of economic crisis and terrorism. Land re-privatization. Declines in coca production (?). Reclamation of abandoned farms (?)

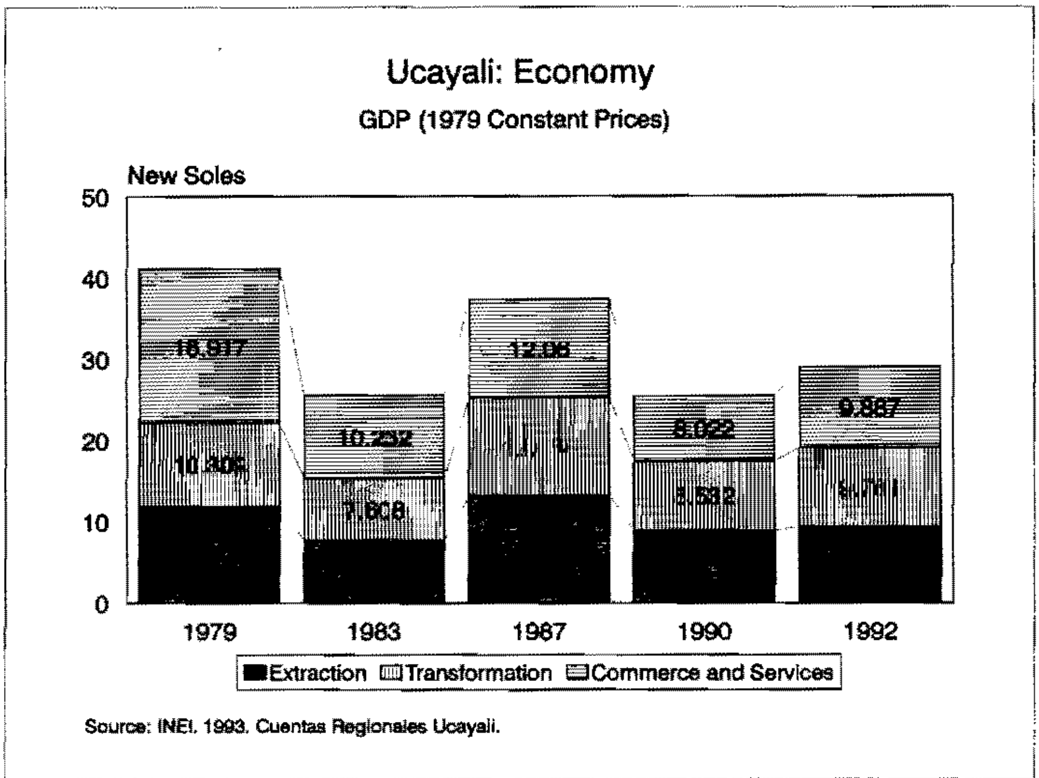


Source: INEI, 1994. Departamento de Ucayali: Perfil Socio-demográfico. Lima. (c. 1.1 & 1.2).

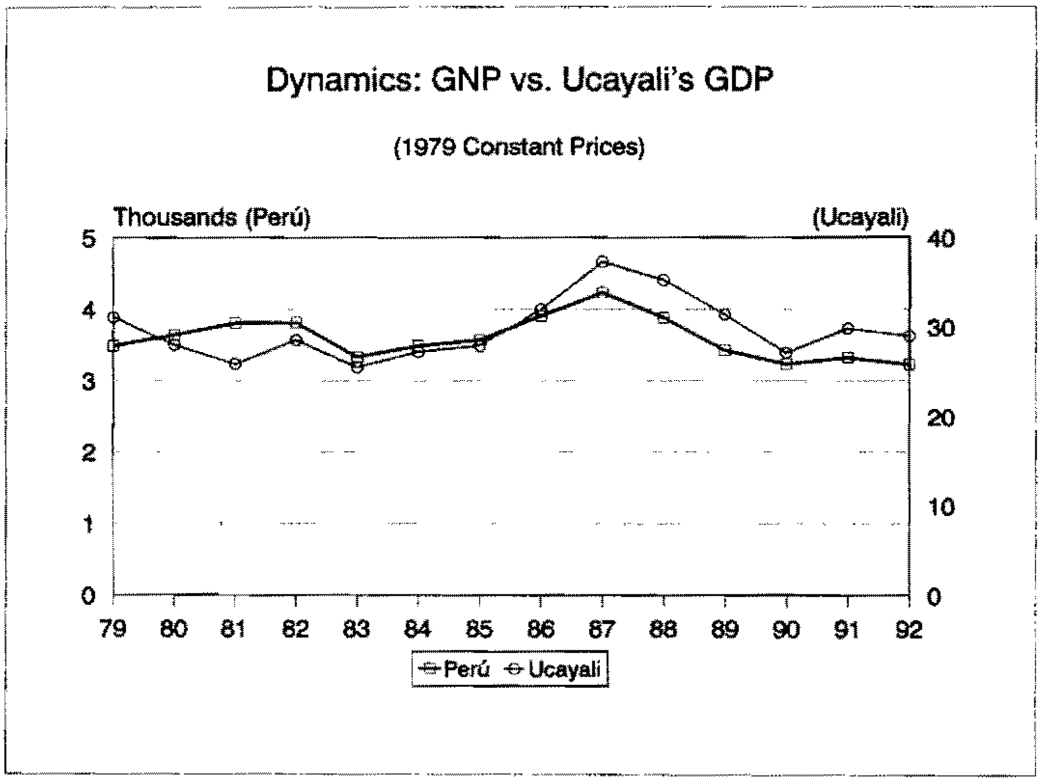


	1940	1961	1972	1983	1993
URBAN	5.332	29.724	67.675	102.66	204.795
RURAL	10.622	34.437	52.826	60.548	110.015
URBAN "PUCALLPA"			62.848	96.892	180.664
RURAL "PUCALLPA"			36.107	42.097	67.795

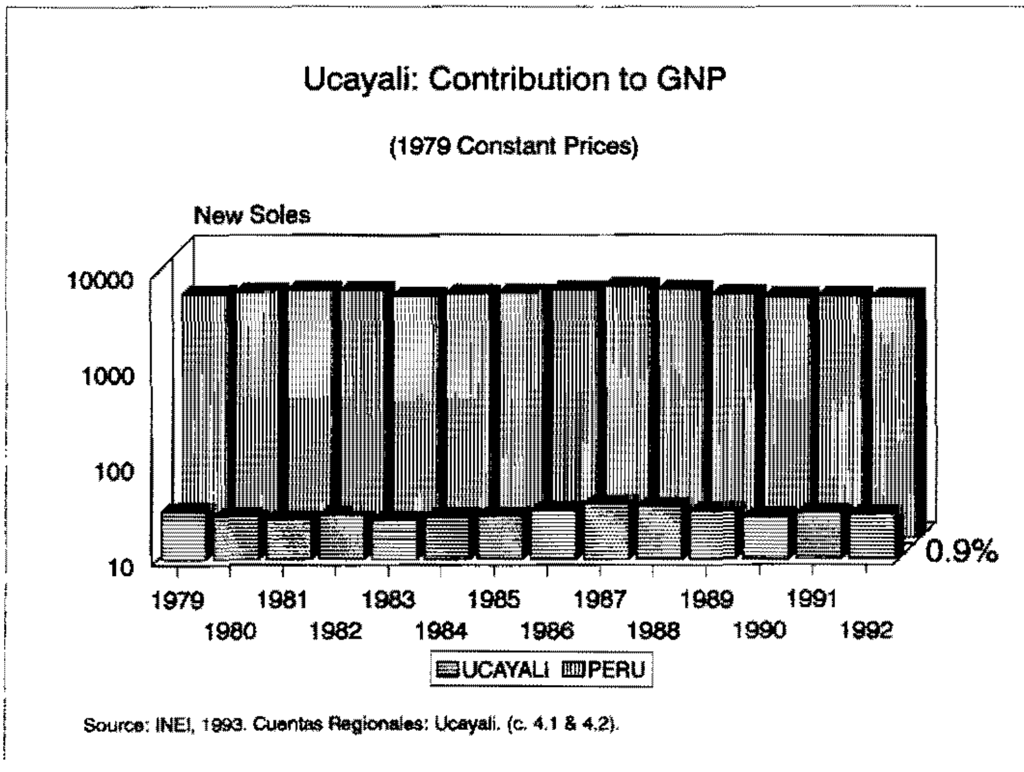
Source: INEI, 1994. Departamento de Ucayali: Perfil Socio-demográfico. Lima. (c. 1.6 & 1.7).

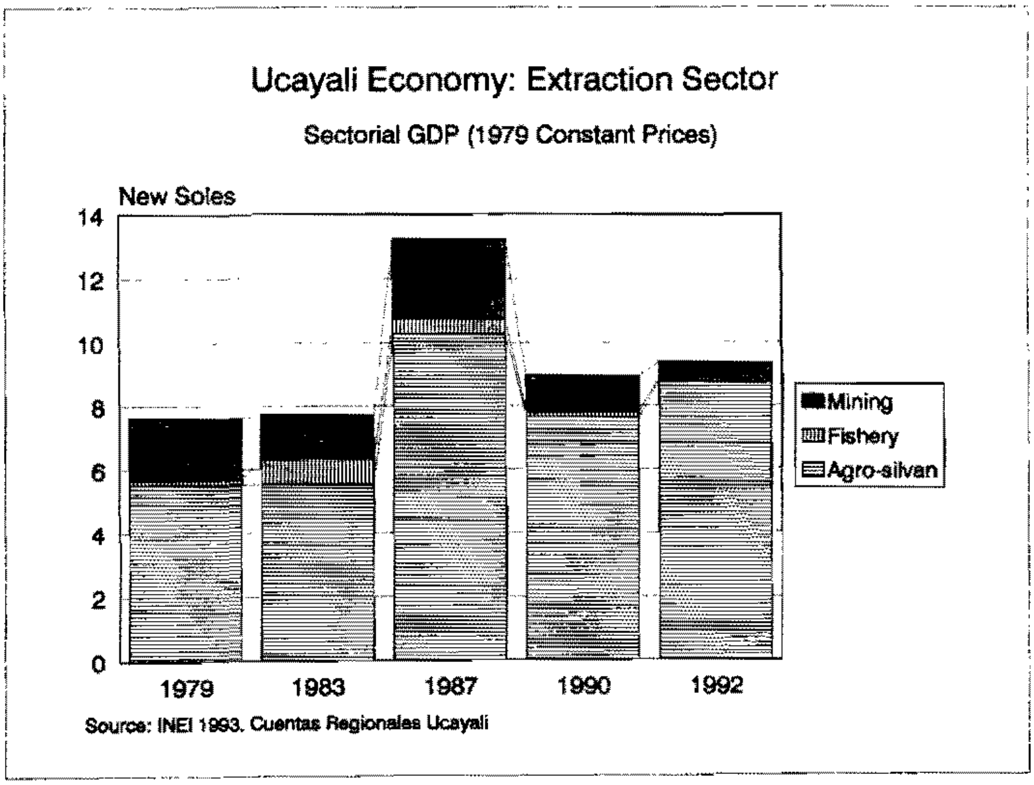


Ucayali: Economy
GDP (1979 Constant Prices)
New Soles
50
40
30
20
10
0
1979
1983
1987
1990
1992
Extraction
Transformation
Commerce and Services
Source: INEI. 1993. Cuentas Regionales Ucayali.



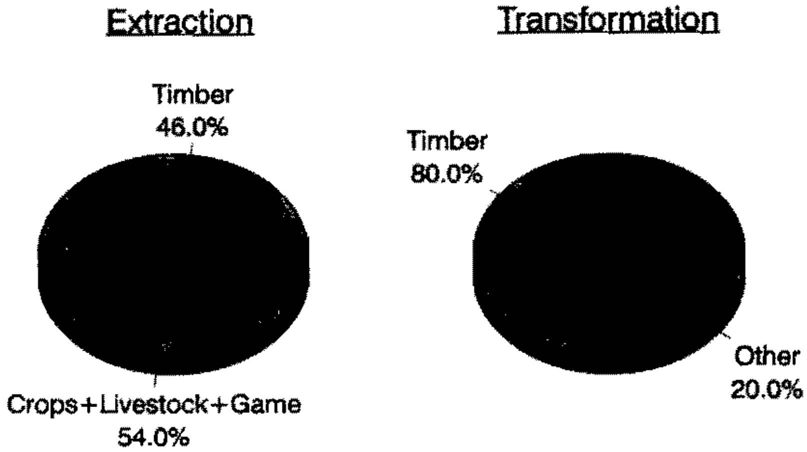
Dynamics: GNP vs. Ucayali's GDP
(1979 Constant Prices)
Thousands (Perú)
(Ucayali)
5
4
3
2
1
0
40
30
20
10
0
79
80
81
82
83
84
85
86
87
88
89
90
91
92
Perú
Ucayali


Ucayali: Contribution to GNP
(1979 Constant Prices)
New Soles
10000
1000
100
10
0.9%
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
UCAYALI
PERU
Source: INEI, 1993. Cuentas Regionales: Ucayali. (c. 4.1 & 4.2).


Ucayali Economy: Extraction Sector
Sectorial GDP (1979 Constant Prices)
New Soles
14
12
10
8
6
4
2
0
1979
1983
1987
1990
1992
Mining
Fishery
Agro-silvan
Source: INEI 1993. Cuentas Regionales Ucayali

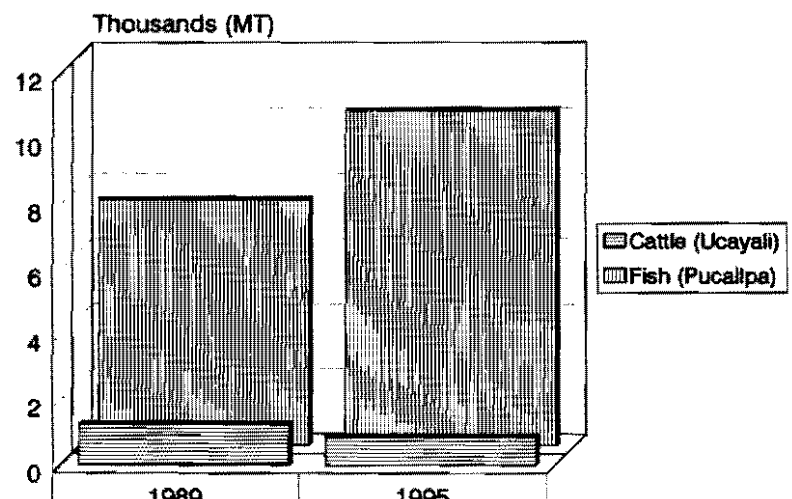
Ucayali Economy: Importance of Timber

Contribution to 1982's Sectorial GDPs



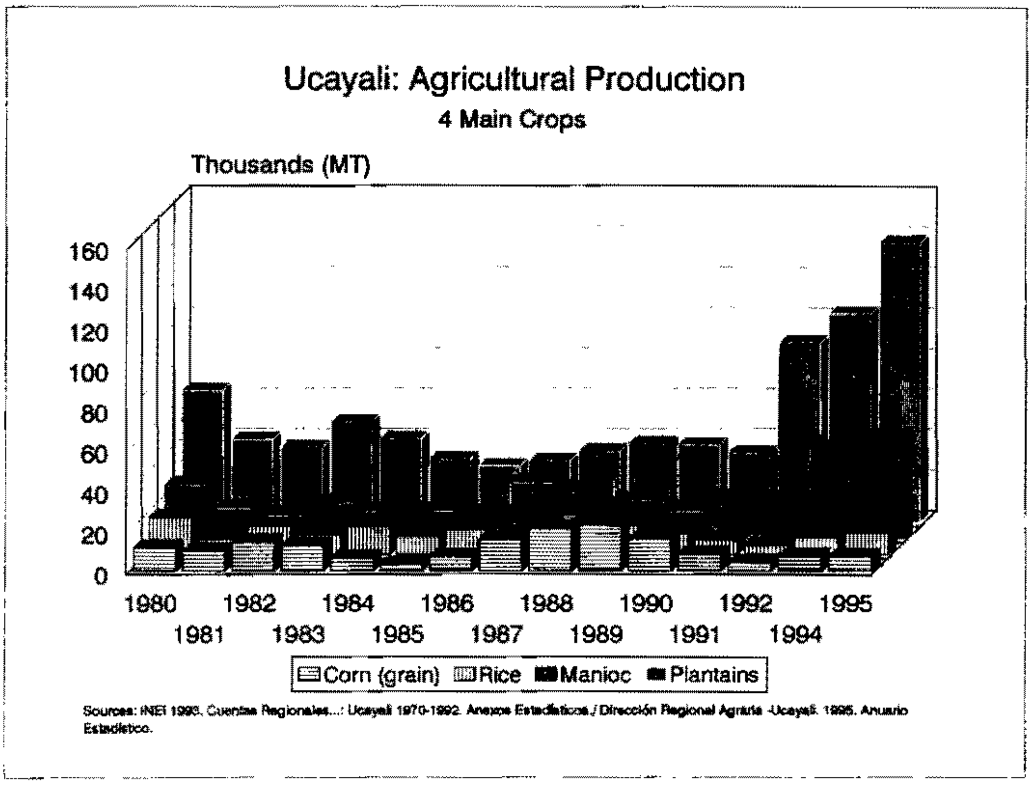
Source: INFOR. 1986. Diagnóstico de la Actividad Forestal del Departamento de Ucayali.

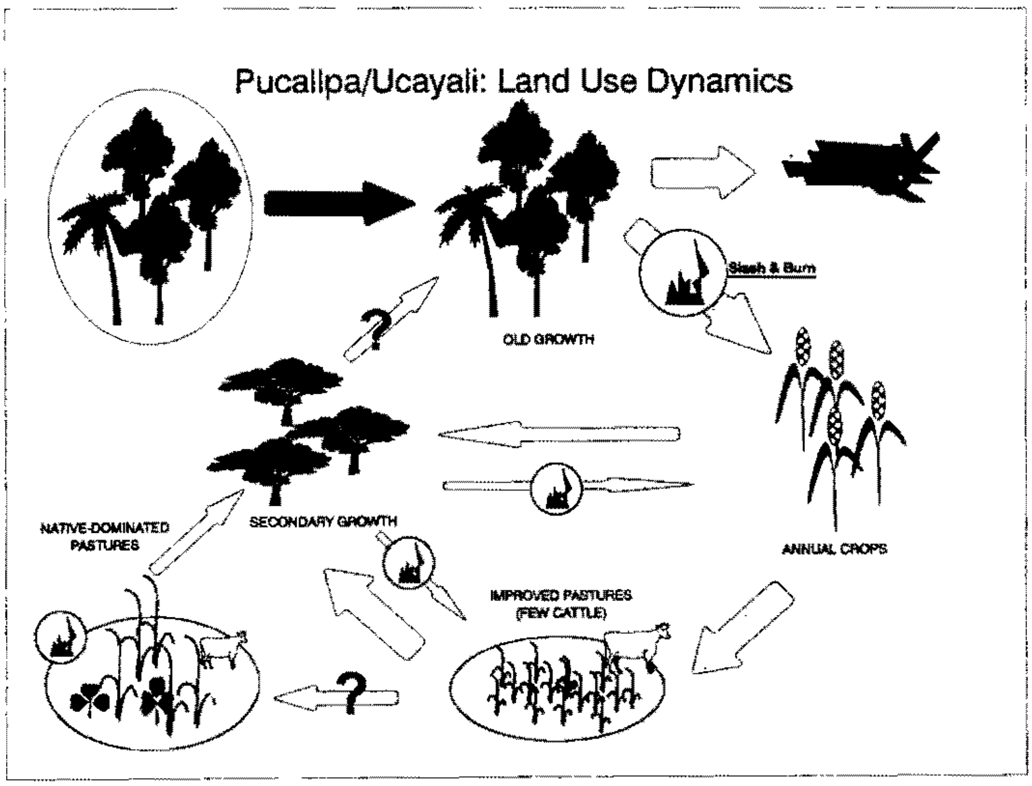
Ucayali: Animal Protein Production



	1989	1995
Cattle (Ucayali)	1.238	0.843
Fish (Pucallpa)	7.534	10.2546

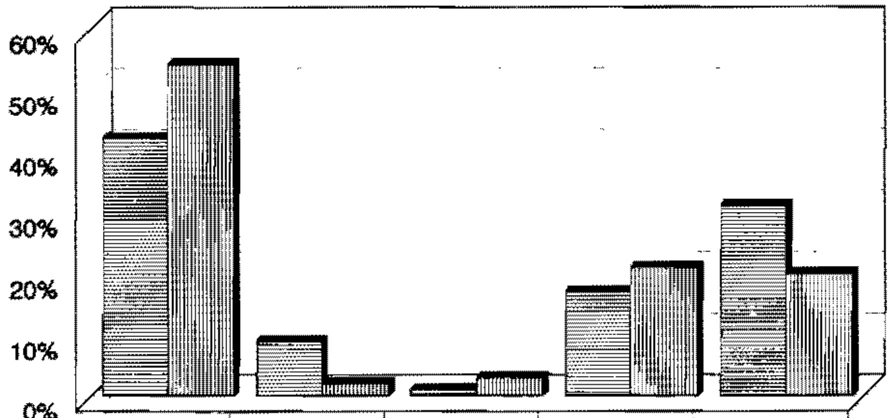
Sources: Proyecto de Capacitación, Extensión y Divulgación Forestal, 1991. Temas Forestales No. 11./ Dirección Regional Agraria - Ucayali 1995. Anuario Estadístico./ Saavedra, 1996 (MS). Diagnóstico de la act. pesquera en la región Ucayali.


Ucayali: Agricultural Production
4 Main Crops
Thousands (MT)
160
140
120
100
80
60
40
20
0
1980 1982 1984 1986 1988 1990 1992 1995
1981 1983 1985 1987 1989 1991 1994
Corn (grain) Rice Manioc Plantains
Sources: INEI 1996. Cuentas Regionales...: Ucayali 1970-1992. Anexos Estadísticos./ Dirección Regional Agraria -Ucayali. 1996. Anuario Estadístico.


Pucallpa/Ucayali: Land Use Dynamics
Slash & Burn
OLD GROWTH
SECONDARY GROWTH
NATIVE-DOMINATED PASTURES
ANNUAL CROPS
IMPROVED PASTURES (FEW CATTLE)
?
?

Pucallpa: Land use pattern

Land Use (% of area) in Cattle Farms, 1982 vs. 1996



	Pastures	Annual Crops	Permt. Crops	Secondary	Old Growth
1982	42%	9%	1%	17%	31%
1996	54%	2%	3%	21%	20%

Source: Zaldivar 1989 (n = 70; farm size = 59.2 +/- 45.7 Ha); Fujisaka 1997. Unpublished data (n = 23; farm size = 67 Ha).

SOCIAL ACTORS

- Government
  - Central (Lima-based top policy makers and technical staff)
  - Regional (centrally-elected bureaucrats and technical staff)
  - Municipal (democratically-elected public officers)
- Citizenship
  - Timber: extractors (small / large), industrials, middlemen; CNF
  - Agricultural producers (incl. coca producers)
  - Merchants
  - Artisanal fishermen
  - Drug dealers
  - Urban dwellers (incl. displaced population in Pucallpa shantytowns)
- Civil organizations
  - NGOs and grassroots organizations
  - Education and research organizations (University, research institutions)

R&D IN PUCALLPA-UCAYALI

- Institutions
- Available Technology
- Traditional Approach to R&D

R&D Institutions in Ucayali

- NARs
  - IVITA: Cattle production (since ~1983, small producers)
  - INIA: Cattle production, agroforestry, silviculture
  - IIAP: Research in natural resources, aquaculture, and agroforestry
  - University of Ucayali: Agronomy and Forestry.
- IARDS
  - CIAT: Cattle production: forages, degraded pastures (small to medium producers)
  - ICRAF: Agroforestry
  - CIFOR: Carbon sequestration markets, management of secondary forests.
- Development Agencies
  - IDRC / CIID: Agricultural research; institutional development
  - UNDP: Oil palm (alternative development)
  - IICA-GTZ: Alternative development
  - USAID: Control of coca production

Agricultural and NN. RR. Technology in Ucayali

- Improved grass-legume pastures for double-purpose cattle
  - CIAT / IVITA
- Agroforestry: Reforestation with timber and industrial species, alley cropping (experimental)
  - ICRAF - INIA, IIAP, Reforestation Committee, Oil Palm Grower Asso.
- Integrated Organic Farming (earthworm-compost horticulture, aquaculture, small farm animals)
  - IIAP
- Sustainable logging and Silviculture
  - INIA - INRENA - ITTO
  - CNF - Netherlands (secondary and "residual" forest)
- Region-level Sustainable Land Use Plans
  - Regional government (?)
  - Swiss cooperation / CDC-Perú
  - IIAP and other

R&D Traditional Approach

(National and International)

- Top-down
  - Farmer knowledge / rationality underestimated
- Gender-biased toward males
- Oriented to product maximization
  - Farmers' and regional priorities overlooked
- Sectored, oligo-disciplinary
  - Economic evaluation often missing
  - Ecological evaluation always missing
  - Context (national / global) missing
- Environmental issues not addressed

SYNTHESIS

- Socioeconomics
- Ecology

Pucallpa-Ucayali: Socioeconomic Synthesis

- Agricultural frontier in the Andean (Western) Amazon
  - Colonist majority, unrooted and marginal. Native cultures decimated: "Ecological blindness" (?)
  - Uncertain / Risk-prone environment (terrorism!): Risk aversion.
  - Subsidy & Boom-oriented economy (cocal): Opportunism.
    - Subsidy from nature: timber, fish, game.
  - Diversified and uncertain production. (Increasing agricultural prod.?)
  - Low institutional development. Particularly at grassroots.
  - Low market development. Extra-regional dependency (?)
  - Extractive, extensive, low-technology production.
  - Labor and capital scarcity (?)
  - High relative poverty, urban-concentrated; although livelihood better than in highlands and larger cities.
- Perú: Macro-economic bonanza. Neo-liberal policies. Latent social violence.
- World: New attitudes and possibilities for holistic R&D and sustainability.

Pucallpa-Ucayali Ecological Synthesis

- Extensively exploited old-growth forests, defaunated and wood-impoverished (genetically eroded).
- Slowly increasing deforestation (carbon emissions).
- Encroaching secondary growth and low-productivity pastures in most densely human-populated area.
- Extensive loss of productive capacity and economic value of land.
- Increasing uncontrolled fresh-water fisheries. Severe risk of over-exploitation.
- The only region in the Peruvian Amazon without protected areas. Three areas in Ucayali considered of highest conservation priority (FANPE 1996).
- Pucallpa area considered environmentally critical based on deforestation, top soil erosion and water pollution (UNCED 1992).

Sources: Gonzales 1995 in Hajek. / FANPE, 1996. Biodiversidad Biológica del Perú.

The State of the Fisheries in the Peruvian Amazon

Humberto Guerra Flores, IIAP

The text below and Figures 1, 2, 3 and 4 are adapted from the presentation given by Humberto Flores. Particular emphasis was given to data describing the case study site, Ucayali.

Aquaculture in the Amazon

Aquaculture Infrastructure in the Peruvian Amazon in 1990, 1992 and 1996

Region	No. of Ponds			Area (Ha)		
	1990	1992	1996	1990	1992	1996
San Martin	224	789	N/A	114.7	271	300
Ucayali	75	135	N/A	53.6	92	125
Loreto	118	286	N/A	34.8	90.4	160
Total	417	1220	N/A	203.1	453.4	585

Cultivated Species

Native

Colossoma macropomum
Piaractus brachipomus
Prochildus nigricans
Brycon erythropterum
Pseudoplatystoma fasciatum
P tigrimun
Macrovrachlum spp.
Pomacea canaliculata

Exotic

Sarotherodon niloticus
S. hornorum
S. aureum
Tilapia rendalli
Cyprinus carpis
Ctenopharingodon idella
Hiphophthalmichtys molitrix
Macrobrachium rosembergii

Aquaculture Program for the Amazon

The development of aquaculture projects are designed to meet the demand for fish that cannot be met in the lower jungle as well as the low or almost non-existent supply on the higher jungle. The program hopes to create various technological packages that can be adopted by different groups of people.

Scale	Level of Intensification	Methods
Rural: Family	Extensive	Monoculture
Rural: Communal	Semi-intensive	Polyculture
Commercial	Intensive	Associated?

Figure 1:Annual Fishing Activities in the Amazon

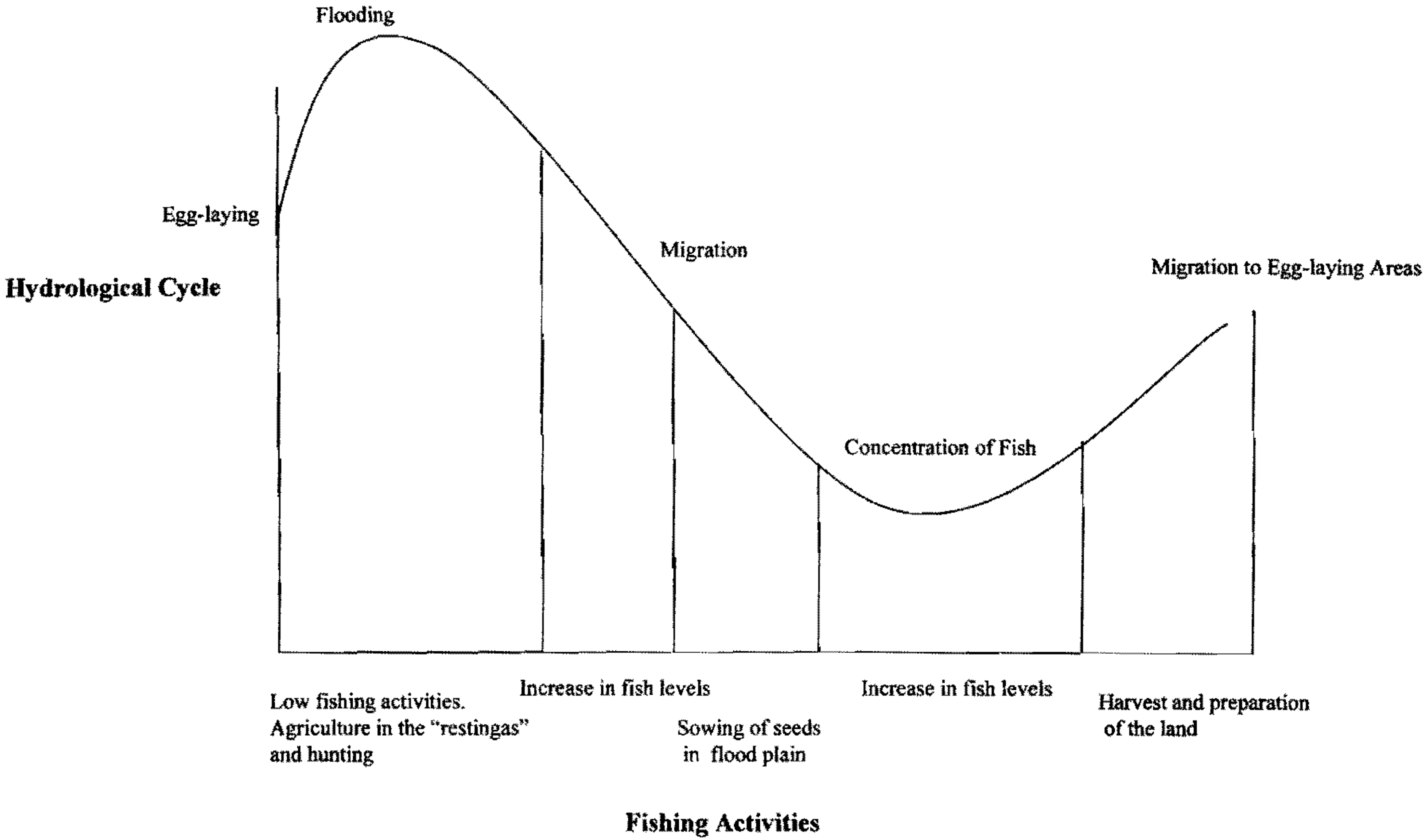


Figure 2: Total Fish Catch in Loreto and Ucayali Regions 1981-1996.

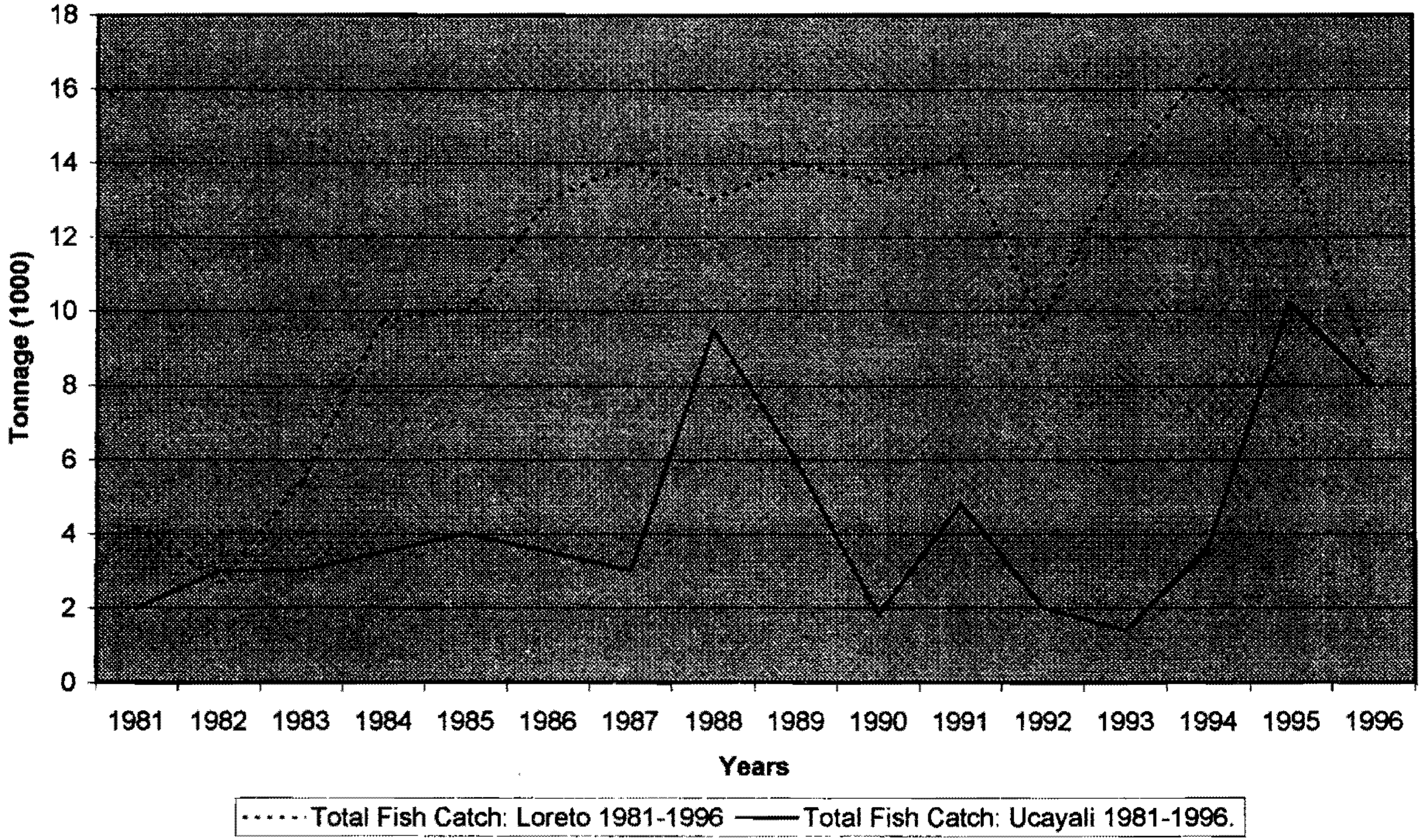


Figure 3: Percentage of Prochilodus nigricans of Total Fish Catch: Pucallpa 1980-1992

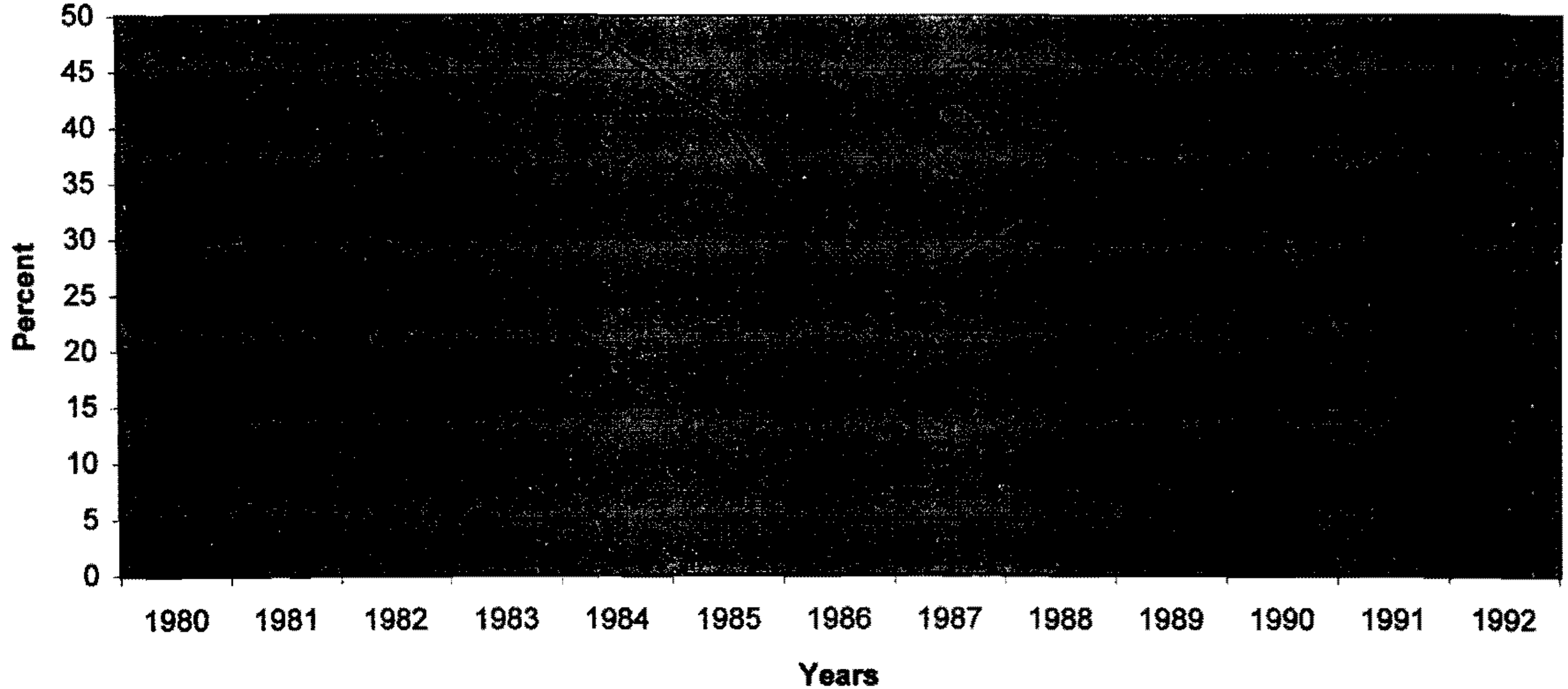
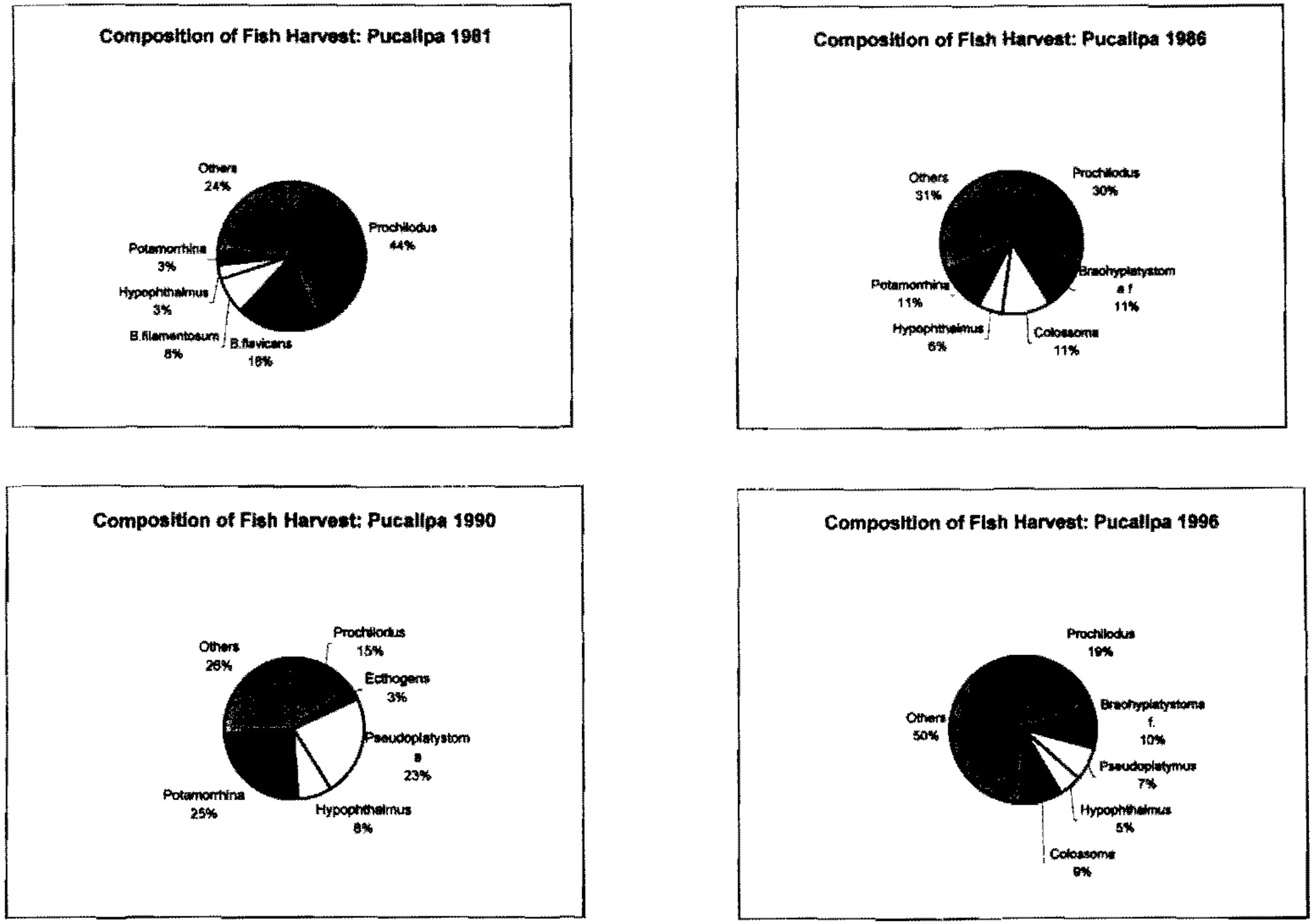


Figure 4


Composition of Fish Harvest: Pucalipa 1981
Others 24%
Prochilodus 44%
Potamorrhina 3%
Hypophthalmus 3%
B.filamentosum 6%
B.flavicans 16%
Composition of Fish Harvest: Pucalipa 1986
Others 31%
Prochilodus 30%
Brachyplatystom a f 11%
Potamorrhina 11%
Hypophthalmus 6%
Colossoma 11%
Composition of Fish Harvest: Pucalipa 1990
Others 26%
Prochilodus 15%
Ecthogens 3%
Pseudoplatystom a 23%
Potamorrhina 25%
Hypophthalmus 8%
Composition of Fish Harvest: Pucalipa 1996
Prochilodus 19%
Brachyplatystoma f. 10%
Others 50%
Pseudoplatymus 7%
Hypophthalmus 5%
Colossoma 9%

Drugs, Producers and Decision-making

Eduardo Musso

1. The Coca-Cocaine Complex[1]

a) Nobody knows how to solve the problem of the illegal coca production.
b) The problem concentrates in rural areas of tropical rainforest regions.
c) More than 20 years of intervention has lead to the conclusion that the coca-cocaine problem is highly complex.

2. Characterization of Economic Actors

a) In the coca territories there exist three types of economic actors engaged in the generation of agricultural productive processes: NATIVES – PEASANTS – ENTREPRENEURS.
b) Agricultural producers are somewhere in between these three types. There are not pure instances of specialized agricultural producers.
c) Native-Peasant actors follow a paradigm based on Process, Context and Space.
d) Peasant-Entrepreneur actors follow a paradigm based on Product, Content and Time.
e) Coca producers are best characterized as Peasants.

3. The Peasants

a) First-to-second generation colonist migrants from the Sierra (Andean highlands).
b) Agricultural producers without capital.
c) Engaged in simple productive processes only.

4. The Ucayali Region

a) Extremely low demographic density.
b) Extensive territories susceptible to colonist invasion.
c) Almost total absence of modern communications and transport.
d) Inadequate legal framework for socioeconomic development.

5. Own Labour as the Main Economic Resource

a) The economics of agriculture is based upon seasonal and biological time frames that are hard to manipulate.
b) Labour cannot be accumulated [it has to be used whenever available].
c) Natural resources are available for free [no monetary value].

6. Productive Strategies

a) Diversified production. Different products are not necessarily grown on the same plot [John Murra's "vertical agriculture"].
b) Maximization of the use of own labor [core and extended family members].
c) Maximization of labor-related profits.

7. The Economic Attitude

a) Money is conceptualized as a means of exchange rather than as a measure of value.
b) Expenses used as an objective indicator of total costs [other costs are not considered].
c) Marginal income of labor used instead of profits on invested capital [to assess economic gain].

---

[1] See Figures 1, 2 and 3

FIGURE 1: THE PROCESS OF INDIVIDUAL DECISION MAKING

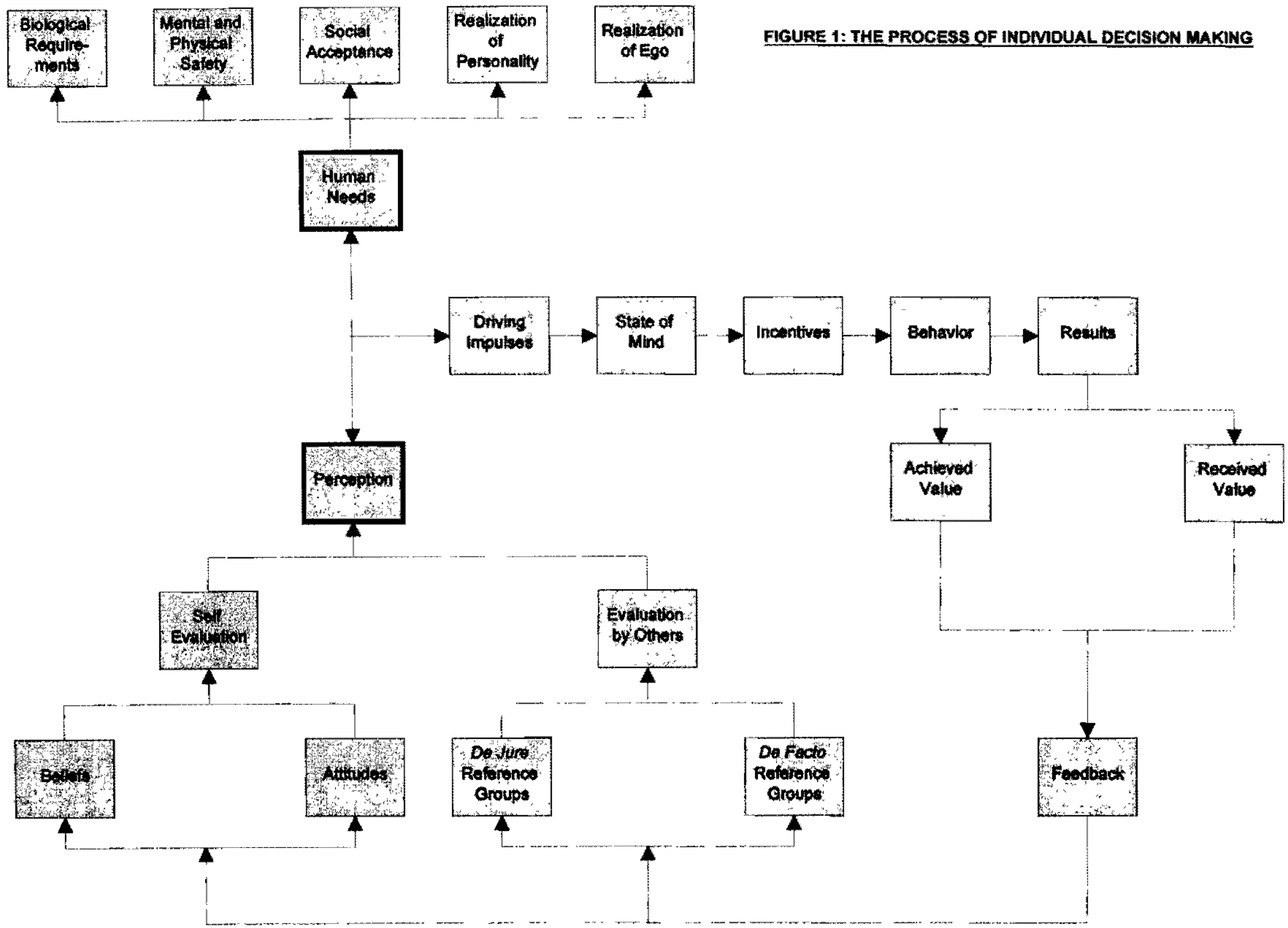


FIGURE 2:TYPES OF DIFFICULTIES

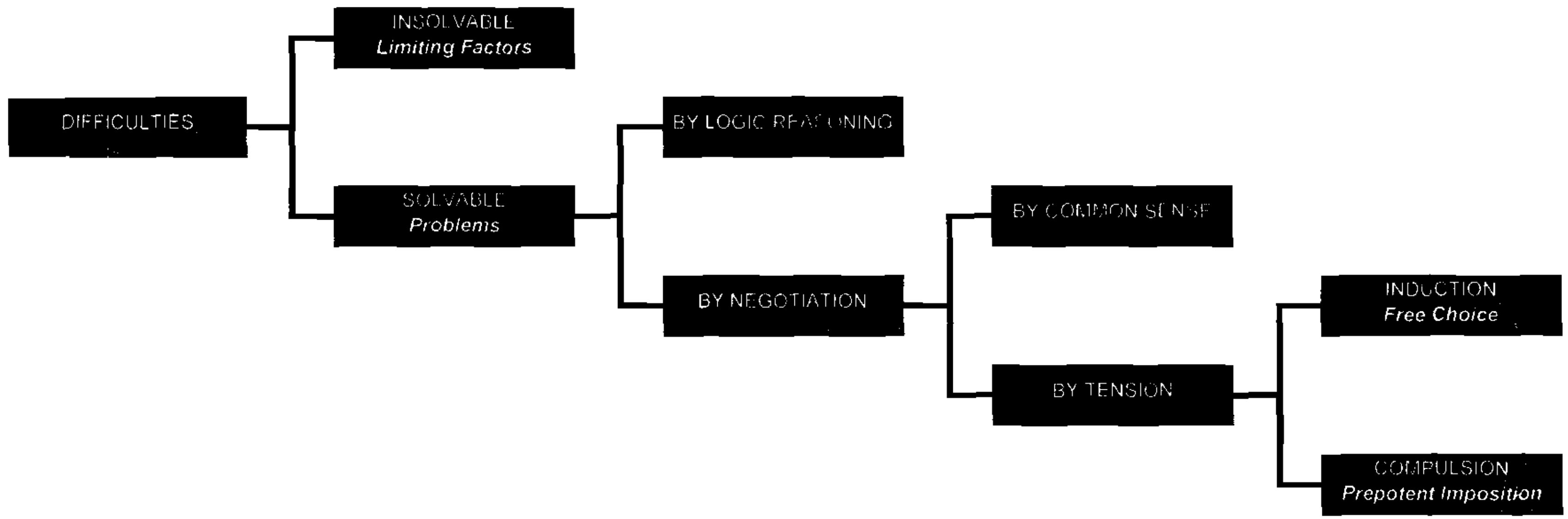
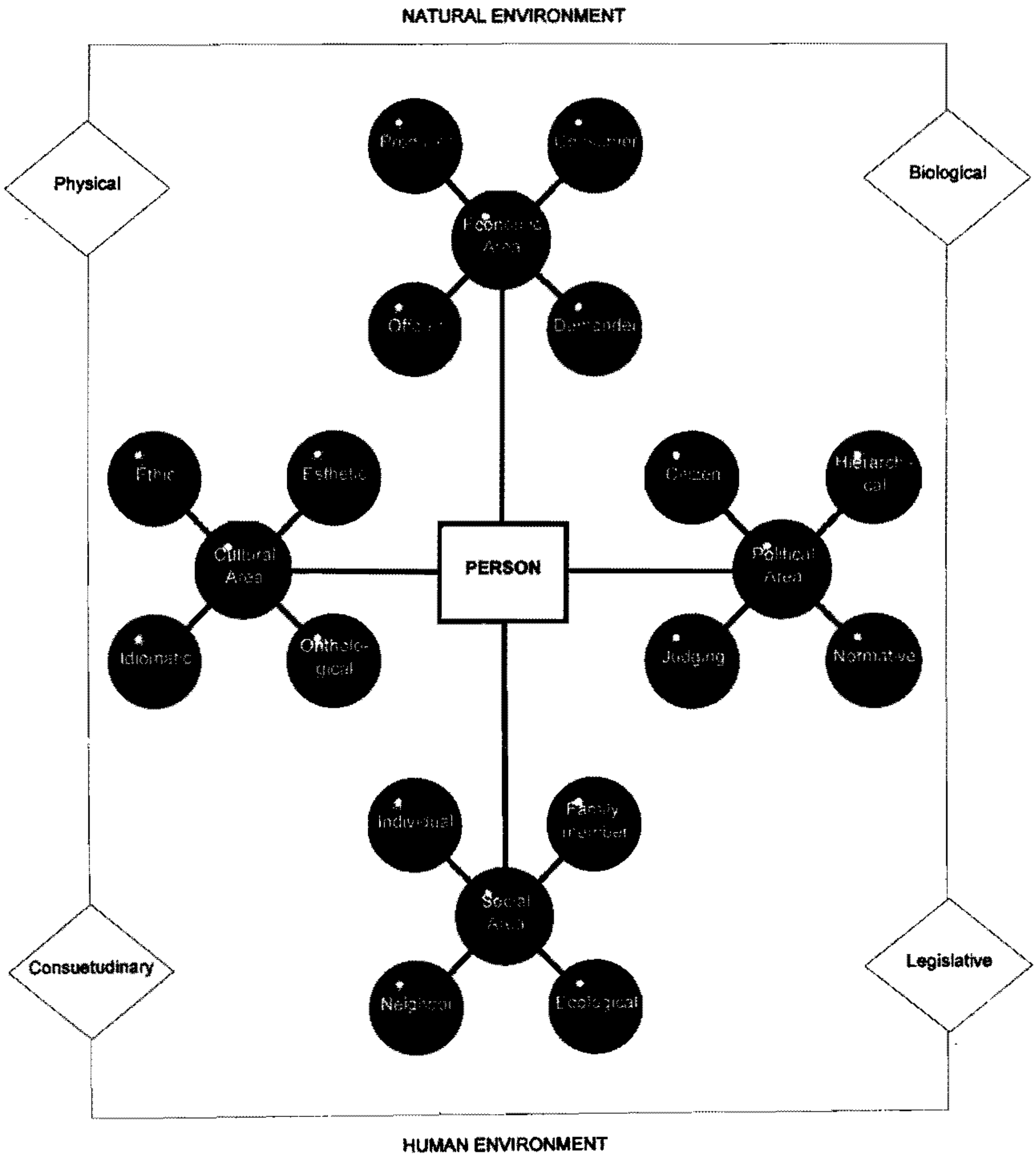


FIGURE 3: FUNDAMENTAL AREAS AND ROLES IN PERSONAL DEVELOPMENT



The Forestry Industry in Ucayali

Miguel Ara, CODESU

1. The Resource Base

Of the total area of more than 10,000,000 ha, 7,430,000 ha is considered suitable for extraction of timber. Geomorphologically this area is represented by high river terraces, and low and medium hills. When taking into account only the tree species currently under commercial use, the potential logging volume of this forestry area is approximately 195,800,000 m3 of raw timber.

Although more than 60 treee species are processed in Pucallpa, five species make up 65% of the raw timber volume.

Most of the raw timber that enters the saw mills in Pucallpa, comes from the south-east of the Ucayali region. Tamaya, a basin located to southeast of Pucallpa, provides 22% of the timber. The upper Ucayali (Pucallpa-Bolognesi and Bolognesi-Sepahua) provide 27%. Approximately 12% comes from the lower Ucayali. Only a small portion of the timber processed in Pucallpa comes from the Aguaytía basin (10%).

Origin:	Tamaya	22%
	Alto Ucayali (Pucallpa-Bolognesi)	16%
	Alto Ucayali (Bolognesi-Sepahua)	15%
	Bajo Ucayali (2 de Mayo-Pucallpa)	12%
	Carretera	5%

2. The Industry

Almost exclusively the forestry industry is based on the processing of raw timber. Of the 256 saw mills, 174 are dedicated to sawing and planing and 54 are only sawing. Other processing that results in greater value added are parquet manufacturing (15 mills) and triplay manufacturing (5 mills).

Most of the mills are individually or privately owned. They are located in the industrial suburb in the city or along the Manantay river, near Pucallpa.

In 1996 the value of the raw material extracted and processed was US$21, 300,358, whereas the value of the processed products for the same period was US$39,041,000. In terms of the contribution of the forestry sector to the regional Gross Product, the two components, extraction and processing contribute 4% and 18% respectively.

Activity	**Number**
Sawing and Planning	174
Sawmilling	54
Parquet manufacturing	15
Barking and boarding	5
Triplay manufacturing	5
Wood, cork and straw products	2
Furniture parts	1
Other products	20
Total	256

3. Problems Facing the Sector

It is the general perception that the main problems of the forestry industry of Ucayali are (a) obsolete technology, (b) inadequate legal and administrative framework, (c) inadequate markets, (d) lack of credit, and (e) lack of entrepreneurship.

(a) Both extraction and processing technologies in Ucayali are obsolete. Most of the logging is done with chain saws and the logs are brought to the rivers and creeks by hand. In the saw mills the tools are not diversified and therefore often the same tool is used for different types of processing. This results in a very inefficient sector in which as much as 50% of the timber is residue.

(b) There are many legal loopholes in acquiring logging concessions and contracts that consequently make administration and regulation of the industry very difficult for the Regional Ministry of Agriculture. Forestry extraction can be done under Extraction Permissions of Extraction Contracts. Extraction Permissions allow farmers to log and clear the area, the initial step in the slash and burn cycle. Rarely are the logged areas that fall under this category recorded. Extraction Contracts are actual logging contracts attained by companies. There are no protected areas in the region. Currently 57% is available for logging by private companies and there are only two areas under the National Forest Regime, which involve extraction but under special administrative conditions.

(c) Marketing tends to be inefficient and complex. There are many actors with significant power and knowledge inequities among them. Market information regarding supply and demand and market prices are generally unavailable. This is especially the case for the extractors, those with the least negotiating power.

(d) Credit is often unavailable for extraction activities. Occasionally those extractors who also own saw mills are able to receive credit, however this occurs only 70% of the time and under strict guarantee requirements.

(e) The lack of entrepreneurship has been emphasized as a significant problem in the sector. The refusal to invest in technological innovations and the inability to promote new market opportunities are two main components of the problem.

The Use of Natural Resources in the Amazon Region of Pucallpa

Ricardo A. Labarta, ICRAF

Introduction

Pucallpa is the capital of the Ucayali Region, located in the Western Peruvian Amazon Basin. Pucallpa is at 154 m.a.s.l., has an average temperature of 26 degrees C, annual precipitation of 1800 mm, and a population of 172,286 .

The population of this Region has one of the highest growth rates in the Amazon Basin. In the recent years Pucallpa's population has increased 5.3% each year (INEI 1993). Similarly, the economic activities in the zone have been increasing. In the Ucayali Region there are four important activities of resource use. They include; forestry, slash and burn agriculture, livestock and fishing.

The interaction between human and the nature is at present producing a number of serious concerns. Global problems of deforestation, green house emissions and biodiversity loss, create much contention regarding land use in the Amazon high forest. It is therefore important to understand the biophysical and socioeconomic processes that are a product of the intervention of various economic agents in the Amazon high forest.

This presentation describes one of the main economic activities in the Ucayali Region, shifting or slash and burn agriculture. The different economic agents involved in this activity and the interrelation between activities and economics agents are explained. This information is based on on-farm research conducted by ICRAF's of approximately 800 farmers in the region.

Public Policies Affecting Economic Activities in the Peruvian Amazon Region

Governmental policy in Peru has been one of the most important factors that has influenced the settlement process in the Peruvian Amazon Region and the development of the extractive and productive activities in the region. There existed 3 different periods, each driven by different development paradigms.

1. **"The settlement policies" (1960-1980).** During this period there were several governments that ranged from left-wing to liberal and moderately right-wing. These governments believed that the Amazon Region would solve the problem of national food security and contribute largely to the development of the country. The principal policies in this period were:
   - Construction and improvement of penetration roads into the Amazon Region.
   - Exoneration from various taxes of the region.
   - Selective credit for specific economic activities (like forestry)
   - Improvement of the basic infrastructure in the region (i.e. schools, electric energy,)
   - Technical assistance for the local producers (given by INIA, Ministerio de Agricultura).

2. **"The protectionist policies" (1980-1990).** This period is characterized by democratic governments facing several challenges and increasing popular demand for a lower cost of living and greater employment opportunities. Social violence and the coca economy were other important factors that influenced this period. The main policies were:
   - Increase in the exoneration of taxes for the Amazon Region
   - Strong protection of domestic production (high import taxes, tariffs). Particularly after 1985
   - Credit subsides for specific annual crops; rice, maize, and beans (selected by government with the criteria of strategic products for cities and industries). In real terms the interest rate was always negative.
   - Prices guarantees for the producers (higher than market prices) and controlled prices for the citizens (lower than market prices).

- Subsides for agriculture inputs (fertilizer, etc).
- Governmental monopsony for some annual crops (ensure market)

3. **"Stabilization of the Economy" (1990 till present).** The previous policy period caused significant problems for the national economy. These included; distorted market prices, hyperinflation and government debt. In addition social violence was increasing. In 1990 Fujimori instituted a dramatic program, intended to stabilize and liberalize the economy, that sent major shocks through the country. Some of the principal policies that affected the Ucayali region were:
   - Elimination of all subsides in the economy
   - Prices determined by the market
   - Liberalization of international trade (reduction of taxes, elimination of tariffs, etc). This meant the entrance of products with less expensive prices.
   - Liquidation of the Banco Agrario, the only source of credit for the farmers. Since 1991 there are not alternatives for credit for the producers in the region. Commercial banks are not an available option.
   - Huge increase in transportation costs. Gasoline increased 30 times (form US$ 0.10 to US$ 3.00).

The Migration Process in the Amazon Region of Pucallpa

The different policies previously described determined to a large degree the process of settlement in the Amazon region. Pucallpa's population rose from 2,000 to 200,000 from 1940 to 1990. At the beginning of this period the population were mostly native (Shipibo-Conibo group) but currently the colonists make up the majority of the population in the region. Most colonists on average have spent less than 30 years in Ucayali.

The principal causes of the migration process can be summarized as:
- Scarcity of lands for cultivation in other regions (particularly the Andean Region)
- Increase in coca production. In the lower jungle this activity demands much labour and provides high revenues to producers.
- Increased activity in the forestry sector. This is the most important activity in the formal economy.
- Explicit policy of the government for the settlement and development of the Amazon Region.

However, the settlement process was not homogenous and among the colonists there are different groups with different characteristics:

a) Colonists from direct migration. They came principally from the Andean Region and from the Pacific Coast. The first group has agriculture experience but do not know much about the local agroecological conditions. They have to adapt part of their traditional technology to the new conditions. The second group does not have agricultural tradition and also they are not accustomed to the special agroecological conditions of the jungle. The main reason for their migration is coca production and timber extraction.

b) The colonists of second migration. They came principally from the Selva Alta (high jungle) . Their parents have come originally from the Andes. They are aware of the local agroecological conditions. The process of adaptation for this group was easier to the conditions of the Selva Baja (lower jungle) .

c) Colonist from internal migration. They are colonists established in the Selva Baja before. They change their actual location for different reasons: better integration with regional markets, searching better roads, flooding of their farms, decrease of the soil productivity, etc.

This settlement process has had negatives social impacts. Most of the native groups have disappeared or their societies have been undermined. On the other hand, the new settlers or colonist have not improved their economical social and environmental conditions of living. (Brack 1994).

The Principal Economic Activities in the Ucayali Region

1. **The Forestry Industry**
2. **The Slash and Burn agriculture**
3. **Livestock**
4. **Fishing**

In many cases, all of these activities are practiced by the same producer with a rationality of minimizing risk. But also there is specialization in all of these activities that implies specific agents with specific behaviors. This presentation centres its description on slash and burn agriculture.

Slash and Burn Agriculture

This economic activity is responsible primarily for deforestation in the Amazon Region. Land is cleared for crops and left to fallow after harvest. Over time land productivity declines and more land is needed to maintain the same level of output.

The Ucayali Region is characterized by predominantly small farmers. However the concept of small farmers is not based only on the size of the farm. It is more important to know the real productive capacity of a family with given production factors (labour, capital, technology). Also it is important to keep in mind the fragility of the soils. Taking this kind of characteristics the farmers in the Region are principally small with less than 20 hectares.

Actually in the typical zones of slash and burn agriculture, the farmers manage farms with 22 hectares and have under production 28% of this area. The land uses in this area can be divided in annual crops, perennial crops, pasture, fallow and primary disturbed forest.

Five different groups of producers can be identified:

- The cattle ranchers settled along the main road.
- The slash and burn farmers of the uplands.
- The slash and burn farmers of the rivers
- The farmers with principally perennial crops
- The natives a long the rivers

All of them have particular conditions and plan their investments depending on their location, the agroecological conditions, the road and market accessibility, etc. In each farm, depending on the described characteristics, the producers of slash and burn agriculture have 3 types of activities:

- The production of cash crops. This includes annual and perennial crops. The principal crops are rice, maize, exotic fruits, etc.
- The production of some crops are for family consumption. In this group cassava, plantain and native fruits are the most important. However in a recent study, plantain has the most important economic value for the farmers and it is the main source of cash income among the families in the Region.
- Complementary activities for get cash resources such as fishing, temporary jobs, etc

The average farmer starts the agricultural cycle in June, taking the decision of the use of new areas (from high forest and fallow) and the quantity of land he/she needs. They will select different land uses and several crops as they have an explicit strategy of spreading risk through diversification. One of the most important factors in the decision making process is labour demands. Each year an average farmer slashes and burns 1 or 2 hectares from the high forest and a similar amount from fallow. In both cases the main objective is annual crop establishment.

For cropping after forest clearing, the farmers prefer rice and for the cropping after fallow maize or cassava. Most farmers usually associate the main annual crops with cassava or plantain. A new area is used on average for 2 years. After the crops the land is put in fallow. The period of the fallow depends on the intensity of the land use of each farmer and ranges from 2 years to 10 years (the average is 3.5 years). In recent years land pressure has been increasing and the period of the fallow is shorter. This is due to decreasing soil productivity, the lack of new areas with high forest in the farms and a decline in crop prices.

After the fallow period the local farmers have 4 ways to continue the land use:

- To continue the agriculture cycle, slashing and burning the fallow and establishing annual crops, but with the expectation of less yields
- To establish perennial crops, especially, exotic fruits. This land use let the farmer has an alternative source of income and avoid the high demand on farm for the family labour. Other kinds of trees have constraints for their establishment because they have a long period before there are returns on their investment (Brodie and Labarta 1997).
- To establish pasture with the purpose of become a cattle rancher or to have an alternative source of farm income.
- To establish pasture or other type of cover for keep a lot cleared and in some way with the idea of a short improved fallow. The use of the legume kudzu is the best example in the region.

In spite of these other land uses associated with slash and burn agriculture, farming is on the whole unprofitable, and farmers continue practicing this land use and continue encroaching on the rain forest. If economically speaking slash and burn agriculture is not profitable, why do most of farmers continue with this activity. The answer is complicated but there are several causes that drive the farmers in this direction:

- Lack of flexibility for other land uses. There are not alternatives that provide better land productivity for farmers. Alternatives like agroforestry are having a lot of problems and farmers are not adopting these alternatives.
- Activities like coca production and illegal timber extraction generate distortion among the local family economy.
- Government policies that encourage farmers to slash and burn agriculture.
- Finally the most important reason; the subsidy of the family labour to the productive process. The use of family labour allows the family to continue an almost economically unviable activity as the labour is available and involves no cash outlays.

The Land Market in the Ucayali Region

The main characteristic of the region is the availability of land. The local farmers and new colonists view the rain forest resources as infinite. There is a relative scarcity of land near the principal cities and near the main roads of the region, but the idea of the abundance of land is continually present.

Initially all the land in the high forest was owned by the government. The use of the land starts with timber extraction. The Government gives to the timber extractors some licenses for the exploitation of timber. After a period the land returns to the "Government control". The timber extractors use the existing roads and build new ones for the far lands. After the exploitation of timber, the colonists begin to take possession of the lands using the old and the new roads constructed. When they arrive to the land they do not have the authorization of the Government. First they define the extension of the land they want to have. With increasing social pressure, the Government gave them a special authorization called "Certificado de Posesion". With this document, the farmers could access to credit and other governmental programs. This process meant the land had no cost for the farmers.

With this Certificado de Posesion farmers can sell and buy land, but never transfer the ownership of the land. When a farmer bought a farm they are only buying the right of use of the land. These sales and purchases were the causes of constant migration in the zone.

Land prices are determined by the market. Among the farmers the most important characteristic is that the cleared areas or fallow have more value than the primary forest areas. This responds to the need to save labour costs (the most scarce factor on farm). In a last survey taken by ICRAF, it shows that some farmers give a value of US$40 for a hectare of primary forest and a value of US$ 80 for a hectare of fallow. In addition, the prices of the land depends of the presence of perennial crops, the establishment of pasture, the proximity to Pucallpa or to a road, etc.

Only the Cattle ranchers have an official ownership of the land. The rest of the farms only have certificado de posesion. The Government has started a new program for give official ownership of the land to all of the producers.

The Labour Market

In this market the labour supply is very heterogeneous. Another characteristic is that the labour market for non agricultural labour is reducing, because the public employment and other sources of employees are decreasing after the stabilization of the economy. The majority of the urban workers are in the underground economy.

Related with the activities linkage with the natural resources use, the timber industry demands the most quantity of employees for the sawmills and for indirect services. In agriculture and in other extensive activities there is a lack of labour most of the year, but the capacity of employment of the rural families is reduced. This low real demand for labour has kept the salary at a very low level (from 2 to 4 US$ per day).

Agricultural labour is provided mainly by the family. Also within the community there is a reciprocal system in which they share labour resources and exchange time on each farm. This is called Chova-Chova or Minga (two quechua words). These are two old labour systems practiced by the Andean cultures. These systems function very well in non market labour systems. Paid workers are used as a last resort.

Family labour is the main factor of the productive unit. The father, the mother and children over 14 years participate. The children from 8 to 14 years combine agricultural tasks with school. The father and the sons slash the new areas, control for weeds and harvest the crops. The wife and daughters have domestic tasks and support the men in the crop harvest. The children younger than 14 years participate in the weed control.

Key Ecological Processes in Ucayali

Erik Veneklaas, CIAT

Short ecological characterization of the Pucallpa area and 'environmental services'

The study region near Pucallpa is located in the Peruvian Amazon. The climate is hot and humid with an annual precipitation of 2000-3000 mm and a dry season of about two months. Three physiographic units are distinguished, which differ in land use patterns: (1) the floodplain, with a strong influence of the rivers, annually flooded, with relatively fertile soils; (2) the resting a, which is potentially flooded for a short period; (3) the upland terraces, the most extensive, least fertile and moist parts. The contingent valuation study was limited to these terraces. Soils here are acid and low in nutrients (Ultisols).

The area has been colonized several decades ago and is connected by a road to Lima. There has been a strong human influence for many years: the landscape is a mosaic of forests, fallows, cropped fields and pastures. There are no primary forests left: they are either exploited (impoverished and disturbed due to timber extraction) or secondary (regrowth on lands where clearcutting and in most cases cropping has taken place). Annual crops are grown after slash-and-burn of forest or of young fallows, and lands may return to secondary forest or be converted to pasture. This pattern of land use is unsustainable; there will be increased pressure on fewer and younger fallows which upon slash-and burn will be less productive because soil fertility is not restored. The final destiny of most land will be (bad) pasture. Rehabilitation of these lands would require big inputs for many years. An alternative land use, agroforestry, is expected to extend the productive period of land without depleting the soil resources. This would reduce the pressure on the land per unit agricultural/economic output. Other alternatives like silvopastoral or agropastoral systems were not considered in the present study, but some research is being done in the area.

Loss of productive capacity (degradation) is a serious problem in the area. Other negative effects of current land use (particularly of deforestation), although more of a global nature, are the loss of biodiversity and the emission of carbon. There are no big immediate environmental problems like erosion, pollution etc. Deforestation may lead to hydrological changes, but water availability is not often a problem in this humid climate. Floods occur in the lower parts but are accepted as part of the system and presumably contribute to soil fertility. An effect of land use on regional climate is very difficult to predict. However if rainfall were to decrease, the impact in this region would be potentially great because it would extend the length of the dry season. Erosion does not seem to be a big problem, presumably because the land is relatively flat and seldomly without plant cover. Water quality is not greatly affected by agricultural land use; the use of pesticides and fertilizers is limited. Large scale conversion of the land into cropped fields or pastures might increase the risk of pests and diseases as a result of reduced possibility for biological control. At present, however, the landscape is still quite diverse in terms of different agro-ecosystems.

As to the conservation of natural resources and environmental services in the region, we suggest that this can be accomplished by the preservation of some forest areas (which have the potential to remain or develop into a state similar to primary forest), as well as the adoption of agroforestry practices. In that way, most species could be conserved, and the biophysical processes would be little effected. For example, observations in the area (Fujisaka, Escobar & Veneklaas in prep) show that plant community diversity of exploited forest is still high, and even fallows retain many of the forest species. Data on amounts of carbon sequestered (Ricse et al in prep) suggest that the primary forest contains some 180 tons C per hectare aboveground. Crops and pastures are an order of magnitude lower. For carbon in the soil (about 100 ton per ha in primary forest) the difference is in the order of 2:1. Logged-over forest and agroforestry lands should be expected to be intermediate between primary forest and crops/pastures, depending on their age and the amount of materials extracted. Agroforestry systems, especially multi-store systems which most resemble natural forests in their structure, are characterized by a more diverse and balanced use of the soil resources and by more efficient recycling than in cropped fields or pastures, thus maintaining the productive capacity of the land rather than degrading it.

Most relevant ecological processes in the Pucallpa study area

The lands around Pucallpa are clear-felled or logged-over forest ands in different stages of secondary succession. There is a diversity of land uses, ranging from forest to crops and grassland. This is the consequence of three main activities: timber extraction, slash-and-burn agriculture and cattle ranching (often in that order but nor necessarily). The landscape is still diverse in terms of agro-ecosystems, and the near-natural and secondary forests are still diverse in species (with the exception of valuable timber and game species).

I consider there are few immediate environmental problems like erosion or pollution. The main problem is the unsustainability of cropping and pasture practices. There will be a gradual decrease of productive capacity in which loss of nutrients and compaction of soils are important factors. The likely result is increased pressure on the remaining forest and further extension of degraded unproductive lands.

There are aspects of land use that may be considered ecological problems like biodiversity loss and carbon emission, but these are mainly of a global nature. I expect few consequences at the local level.

In ecological terms the productivity conditions are favorable, as shown by the biomass production of the primary forest. The climate (precipitation, temperature, etc.) favors production. The soils have problems but in the natural forest these do not seriously limit its functioning. The problem is that the functioning of the natural ecosystem depends on a delicate interaction of the vegetation and soil organisms. No agricultural system has been found that adequately simulates this, or provides another stable solution. There may be two options: high intensity - low frequency interventions like slash-and-burn agriculture (this system is collapsing due to shortening of fallow periods, i.e. increased frequency), or some stable continuous system in which outputs balance inputs. In the latte case the soil nutrients are probably the limiting factor. 'Natural' nutrient inputs are small due to low soil reserves, meaning that sustainable production can only be high if nutrients are added to the system from outside. If fertilization is not feasible, sustainable systems are bound to be low-input-low-output systems. Perennial crops and pastures may be examples. It is expected that there will be advantages to these 'crops' being used in agroforestry or silvopastoral systems, which resemble more the natural ecosystem.

A critical process that must be maintained by any land use in order to be sustainable, particularly in regions like the study area, is the cycling of nutrients. Losses of the nutrient stocks (which is coupled with the organic matter content) in the soil must be avoided. The presence of a healthy community of soil arthropods and microorganisms should guarantee efficient turnover of litter inputs and efficient cycling (closed cycles without losses). The vegetation must be continuous and in good condition to guarantee immediate nutrient uptake.

We lack understanding about the factors that determine the fate of abandoned or badly managed lands (crop fallows or pastures). Severely degraded lands may not develop mote than a sparse vegetation cover. Less degraded lands may be invaded by 'weeds' and either develop a persistent species-poor (shrubby?) vegetation or gradually develop into secondary forest. The likely determinants are soil chemical (nutrients, pH), physical (compaction) and biological factors (decomposers, mycorrhizae) and the seed bank and seed influx from surrounding lands.

Dual-Purpose Cattle Production in Pucallpa[2]

Federico Hollmann

Dual purpose cattle production is an important activity of small farmers in most regions of tropical Latin America. However, traditional systems are often marginal in an economic sense (Riesco et al. 1982) and follow land use practices that are not considered sustainable in the long term. In particular, this applies to dual purpose cattle production in the forest margins (Toledo and Formoso 1993). The main limitations to increased productivity are the supply and quality of feed, the milk production potential of the animals and management. Research has identified improved grasses and legumes with the potential to increase livestock productivity per unit area of land (CIAT 1992). This would allow alternative land uses to livestock on the more fragile areas of the landscape. They can be integrated with annual crops (Thomas et al. 1995) or tree crops (Veiga and Serrao 1990) as a component of sustainable land use systems. Major limitations to widespread adoption are lack of information on their utilization and integration into existing feeding systems, and demonstrated economic viability. Further, as small-holders are frequently involved in mixed crop-livestock systems, decision-making about resource use is a complex process.

Meat and milk are considered a basic part of the diet in Latin America (Jarvis 1986). There was a 12% deficit in milk production from 1984 to 1991 (CIAT 1993) and a large deficit of both meat and milk is forecast by the year 2000 (Rivas 1994). Dual purpose cattle constitute 78% of the total cattle and produce 41% of the milk in Latin America (Rivas 1992).

Pasture is the dominant feed for cattle in this region but quality is low and feed shortage occurs with long dry seasons. Improved legumes and grasses of high quality have the potential to increase beef and milk production (Lascano and Estrada 1989; Lascano and Avila 1991). These legume-based pastures have been shown to contribute to more sustainable land use through N fixation (Thomas et al. 1994), rapid turnover of P (Oberson et al. 1995) and increased soil biological activity (Decaens et al. 1994).

The key to increased productivity is research to develop feed production and utilization strategies that will allow improved forages to be combined with natural forages in order to optimize the use of both to overcome nutrient deficiencies. This is a strategy that takes into account the options for animal genotype, land use and the ability of the farmer to implement the new technology.

In the forest margins (defined as areas cleared from primary forest), milk production is limited by the quality of the forage and the ability to maintain sustainable and productive pastures (Toledo and Formoso 1993). While these areas are also used for annual and perennial crop production, no one system is yet considered sustainable in the long term. Thus as well as investigating the potential for legume-based forages to provide a higher quality of diet, there is also the need to evaluate whether they are economically and environmentally sustainable and to what extent they complement other components in a production system. The Pucallpa region in Peru has been selected as a benchmark site for the forest margins. It was selected because of previous research on development of legume and grass forages for the area (Reategui et al. 1995) associated with ecoregional research that is being conducted by the members of the Alternative to Slash and Burn (ASB) consortium and because of the capability of local institutions

The goal of the Tropileche Project at CIAT is to improve the production and utilization of feed resources in a sustainable manner through improving feed quality and supply, developing feeding strategies in crop-livestock systems, improving soil productivity and mitigating soil, pasture and ecological degradation. More specifically the Project intends to determine how to increase efficiency in the use of forage resources for milk and beef production, identify the potential of different forage resources for increasing milk and beef production and provide information on the demand for, acceptability and environmental impact on new forage systems.

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[2] Additional material from "Improved Legume-Based Feeding Systems for Smallholder Dual-purpose Cattle Production in Tropical Latin America: Project Proposal" (1995) has been added to this presentation.

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Land Use Strategies in Pucallpa, Perú*

Sam Fujisaka**

Abstract

In a selected study area in Pucallpa, Peru, 151 farmer-settlers were interviewed to understand current land use dynamics. Respondents were stratified according to broad differences determined by preliminary informal surveys. Settlers included: farmers practicing slash-and-burn agriculture in upper forested areas, slash-and-burn farmers living along rivers, small-scale cattle ranchers with lands located largely along the road connecting Pucallpa to Lima, and a subset of forest slash-and-burn farmers who had established oil palm as a cash crop. This working paper describes land use patterns and differences among these groups. Some of the problems and opportunities faced by each group are considered.

Introduction

Farmer-settlers in the western Amazon practice slash-and-burn agriculture to produce annual crops such as rice, maize, cassava, and beans. Thus, colonists convert primary tropical forest lands to other uses—including pasture for cattle production, perennial crops, and fallows for future annual cropping. Slash-and-burn agriculture of this type has contributed to deforestation, emissions of atmospheric carbon, and losses of biodiversity (Brady, 1996; Fujisaka *et al*, 1997).

Land use in Pucallpa, Peru, was examined as part of a global initiative coordinated by the International Centre for Research on Agroforestry (ICRAF) to develop "Alternatives to Slash-and-Burn" (ASB).

Pucallpa is characterized by humid, tropical forest cover. The site is in the Department of Ucayali (bordering Brazil to the east) and along an east-west gradient leading to the foothills of the Andes along which rainfall ranges from 1800 to 3000 mm (a mean of 2300 mm, with rainfall increasing to the west). Wet months are February-May and September-November; dry months are June-August and December-January. The mean annual temperature is 25 °C. Soils include more favorable alluvial, riverine systems where the pH is about 7.7 and available P is 15 ppm; and higher, well drained forested areas of acidic (pH 4.4), low P (2 ppm) soils. Flatter areas near the city of Pucallpa (but out of the area of interest) are poorly drained (*aguajales*) and dominated by *Mauritia* spp. palms. The Huanuco-Tingo Maria-Pucallpa highway was constructed in the 1940s, but settlement only became substantial in the 1970s with improvements to the highway (Loker, 1993; Riesco and Arroyo, 1997).

Methods

Researchers representing Peru's Instituto Nacional de Investigacion Agraria (INIA), the Centro Internacional de Agricultura Tropical (CIAT), and ICRAF selected the Pucallpa study area. The site was chosen as representative of the different types of slash-and-burn-based agricultural land uses in the broader region.

A multidisciplinary team of researchers from INIA, CIAT, and ICRAF interviewed 151 settlers in Pucallpa in mid-1996. Interviews dealt with patterns of land use and resource management. Responses were coded and data tabulated and presented in simple descriptive frequencies. Farmers described land use allocations for 1995-96 and for 1996-97.

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Preliminary fieldwork showed that settlers were naturally grouped by location (e.g., forest, river, roads) and by major enterprise (e.g., slash-and-burn, cattle, slash-and-burn plus oil palm). Groups included: farmers practicing slash-and-burn in upper forest areas, farmers living and practicing slash-and-burn along the rivers, small-scale cattle ranchers located largely along the road connecting Pucallpa to Lima, and another subset of the forest slash-and-burn farmers who recently established oil palm as a cash crop.

A LandSat TM image from 1993 that showed part of the study site was obtained, classified, and analyzed.

RESULTS

Migration and settlement

Twenty-seven percent of the respondents originated from Pucallpa. Of the others, 30% arrived in the period 1990-95. The remaining 70% of immigrants arrived from before the 1970s up to 1989, with fewer arrivals from 1975 to 1984. Although, overall, the 73% of respondents who migrated to the area had been in Pucallpa for a mean of 16 years, those raising cattle had been there longer (a mean of 24 years)(Table 1).

Land use

Forest and riverine slash-and-burn farmers accounted for 76% of the respondents, had farms of a mean 29 ha, of which the forest farmers had only 27% and the riverine farmers had 46% in forest in 1996 (Table 2). The 15% of respondents with cattle had significantly larger farms (67 ha) of which a high percentage was cleared (80%). Farmers who had planted oil palm had land parcels of the same size (32 ha) as the other forest farmers, but had more land in perennial crops (17%) and less in fallow (24%). These farmers also had the lowest proportion of their farms in pasture (4%).

In terms of all respondents' land use changes from 1995 to 1996 and considering only lands held by the respondents (5249 ha in total), forest decreased from 35% to 33% of the area; and area cleared increased from 65% to 67%. Cleared areas showed marked increases in annual crops and perennials, with only a slight increase in pasture (Table 2).

Analysis of the LandSat TM image largely confirmed farmers' accounts: the image covered 109,100 ha of which 17,300 ha corresponded to colonists' parcels and large haciendas held 7,400 ha. Analysis indicated that 70% of the colonists' parcels were deforested in 1993 (comparing closely to the reported 67% in 1996 once a correction based on parcel sizes was made regarding the depth from the road of farmers' fields).

Most slash-and-burn farmers cleared new forest parcels every year or once every 2 years. Two-thirds of the cattle ranchers, however, cleared forest lands only once every 3 years and a third cleared lands every other year (Table 3). The slash-and-burn farmers (including those with oil palm) cleared means of 1.5 to 2.0 ha per year; and cattle ranchers cleared a larger 2.6 ha per year (Table 4). Overall, comparing respondents that have and do not have cattle, the former cleared forest lands less often, but opened larger areas to grow crops such as rice and cassava for sale.

Farmers reported their criteria for selecting and clearing particular forest parcels. The main reasons given were fertile soil (43% of respondents), no flooding (29%), close to road and/or house (19%), and flatter topography (9%)(Table 5).

Farmers reported needing 20 days ha^{-1} for slashing (prior to and after felling) and 27 days ha^{-1} for felling when clearing forest parcels; and 16 days ha^{-1} for slashing and 6 days ha^{-1} for felling fallowed parcels (Table 6).

Nearly all farmers grew rice in fields cleared from forest in the first year and cassava, maize, pasture, or other crops in the second year (if not fallowed). Farmers sowed rice, maize, cassava, and banana in fields cleared from fallows (Table 7). Although fluctuating by year, farmers overall maintained approximately equal areas sown to rice, maize, and cassava (Table 8).

Farmers reported actual crop yields for 1995-96: the 1.4 t ha^{-1} of rice, 1.7 t ha^{-1} of maize, and 0.2 t ha^{-1} of beans were lower than their reported "normal" yields but higher than previous lowest yields of each respective crop (Table 9).

Fields cleared from forest were cropped for a mean of 2 years: 30% of the respondents cultivated for 1 year, 44% cultivated for 2 years, 16% for 3 years, and 10% for over 3 years. Lands cultivated after fallow were cultivated for a mean of 1.3 years. Respondents discontinued cropping plots cleared from forest because of declining production (major reason cited by 75% of respondents) and weeds (46%).

Combining these interview-based results with more informal field observation and discussions with settlers, each of the subgroups of respondents can be described.

Slash-and-burn farmers of the forest

Forest farmers had a high proportion of their lands cleared (73% in 1996), and the highest proportion (39%) of their farms in fallow or secondary re-growth. Rice was the major crop, and one that suffered from yield-reducing diseases. These farmers had 10% of their lands in perennial crops such as citrus, achiote, cacao, and various fruits. A substantial number grew coca, although demand had declined since the end of the area's domination by the terrorist group, *Sendero Luminoso* (Shining Path). To some extent it appeared that charcoal production has replaced coca production as an income-generating alternative.

Riverine slash-and-burn farmers

These farmers had farms that were 54% cleared and 26% in fallow. Banana was established as a cash crop on the relatively richer soils (compared to upper-forest areas) after initial slash-and-burn rice production. Sikatoka was widespread as a problem in banana, and one that farmers reported may be exacerbated by the defoliants and herbicides sprayed from helicopters in the Peruvian army's efforts to eradicate coca fields. Flooding was a problem, albeit with benefits (i.e., the deposits of richer river-borne silts). River farmers also earned incomes from fish and the softwood, *Guazuma crinita,* which grew in fallows.

Small cattle ranchers

These farmers had the largest parcels (67 ha), the least forest (20%), the lowest proportions of land in annual and perennial crops and in fallow (although they had the largest annual crop fields in absolute terms), and the highest proportion of land in pasture (54%). For the 20% of Pucallpa respondents having cattle, herd size was a mean of 23 head. Pastures were reportedly 40% (of pasture area) *Brachiaria* spp. and 28% *Brachiaria* spp. plus *Pueraria phaseoloides*, although areas of native pasture (of *Axonopus compressus*, *Paspalum conjugatum*, and *Homolepis aturensis*) were clearly underreported. Thirty-nine percent of the ranchers reported using fire for pasture regeneration at a mean interval of every 2 years; and 68% reported rotating animals to different pastures at a mean interval of 1 month. Pressure on pasture resources was low: 73% of these respondents maintained less than one head per ha, 24% had one to two head, and only 3% had more than three head of cattle per ha of pasture. It was widely reported that the period of terrorism by the *Sendero* led to substantial declines in cattle numbers and reduced maintenance of fences and pastures.

Oil palm farmers

These slash-and-burn farmers have accessible upper-area parcels, have taken advantage of local development projects promoting oil palm (*Eleais guineensis*), and, therefore, have the largest proportion of their farms in perennial crops (17%) and the lowest in pasture (4%). The success of oil palm will depend on the development of processing infrastructure and demand, sufficient to maintain prices at profitable levels.

Conclusions: Towards an Appropriate Research Agenda

Overall, Pucallpa farmers relied on rice as a major crop for both sale and consumption. Research to help solve upland rice disease problems, and the problems of soil nutrient depletion and increases of weeds, would benefit many farmers in the area. Pucallpa farmers had a high proportion of their lands in fallow or secondary re-growth. Working with farmers on improved fallows using trees and legumes would appear to be reasonable.

Upper-area farmers who had earned incomes from coca production (from sales and/or from wages for weeding and harvesting) were seeking new alternatives. Charcoal production cannot be expected to be sustainable given the use of selected suitable forest species such as *Dipterix odorata*. Efforts to develop and promote new crops (such as camu camu *Myciaria dubia*) and agroindustries (e.g., palm oil) would appear to be reasonable; and research is needed to carefully determine *ex ante* demand for new alternatives. Farmers have had experience with the promotion of supposedly income-generating crops such as citrus and achiote, which unfortunately were market failures.

Riverine slash-and-burn farmers were most concerned about diseases affecting their banana plantations (and upland rice). Research to address the problem would be appropriate and is needed.

Research in Pucallpa has long targeted the cattle ranchers in the introduction and testing of forage and feeding systems alternatives including legumes such as *Arachis pintoi, Centrosema* spp., *Desmodium ovalifolium, Cratylia argentea,* and *Stylosanthes guianensis,* as well as forage grasses. These settlers, however, may have little interest in more productive forage systems as long as current pasture resources are more than sufficient given the area's reduced herd size. On the other hand, targeted work to increase systems productivity and sustainability with the few ranchers maintaining more animals per area may be appropriate. This appears to be the case with the current work of the Instituto Veterinario de Investigaciones Tropicales y de Altura (IVITA) and the CG project, Improved Feeding Systems for Dual-Purpose cattle (TROPILECHE).

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Table 1. Year of arrival of migrants (% of respondents, n=111) by main economic activity, Pucalipa, Peru.

Year of arrival	Slash-and-Burn Forest (n = 32)	Slash-and-Burn Riverine (n = 54)	Subtotal (n = 86)	Other Cattle (n = 13)	Other Oil palm (n = 12)	Total (n = 111)
1990-95	34	31	33	15	25	30
1985-89	19	13	15	8	33	16
1980-84	9	7	8	8	0	7
1975-79	9	13	12	8	8	11
1970-74	16	17	16	23	17	17
< 1970	13	19	16	38	17	19
Mean	14	17	16	24	15	16

Table 2. Land use (% of area) by main agricultural system, Pucallpa, Peru, 1994-5 (A) and 1995-6 (B).

	Slash-and-Burn						Other							
	Forest		Riverine		Subtotal		Cattle		Oil Palm		Total			
	A	B	A	B	A	B	A	B	A	B	A	B	Change	Resp (%)
Forest	30	27	48	46	40	38	20	20	52	51	35	33	- 5.0	67
Cleared	70	73	52	54	60	62	80	80	48	49	65	67	+ 2.0	100
Pasture	16	16	12	12	13	14	54	54	2	4	24	25	+ 0.5	44
Fallow	43	39	25	26	33	31	22	21	25	24	29	28	- 5.0	82
Annual crops	3	8	8	6	6	7	1	2	7	4	5	6	+ 15.0	80
Perennials	8	10	7	7	8	10	3	3	14	17	7	8	+ 14.0	84
Total area (ha)	1443		1846		3289		1538		422		5249			
Sample size	44		71		115		23		13		151			
(no)	33		26		29		67		32		35			
Farm size (ha)														

Table 3. Frequency (years) of forest clearing by main agricultural systems, Pucalipa, Peru, 1996, in percentage of respondents (n = 52).

Frequency	Slash-and-Burn Forest	Slash-and-Burn Riverine	Slash-and-Burn Subtotal	Other Cattle	Other Oil Palm	Total
1	85	57	71	0	75	69
2	10	29	19	33	25	19
3	0	9	5	67	0	8
>3	5	5	5	0	0	4
Mean	1.2	1.7	1.5	2.7	1.2	1.5

Table 4. Clearing of given forest area (ha) by main agricultural systems, Pucallpa, Peru, 1996, in percentage of respondents (n = 93).

Area	Slash-and-Burn Forest	Slash-and-Burn Riverine	Slash-and-Burn Subtotal	Other Cattle	Other Oil Palm	Total
< 1.0	9	5	7	12	17	8
1.0-1.9	41	39	40	12	42	38
2.0-2.9	29	28	29	26	33	29
> 3.0	21	28	24	50	8	25
Mean	1.8	2.0	1.9	2.6	1.5	1.9

Table 5. Farmer-reported criteria for choice of location of forest field to clear and crop by main agricultural system, Pucallpa, Peru, in percentage of respondents (n = 83).

Area	Slash-and-Burn Forest	Slash-and-Burn Riverine	Slash-and-Burn Subtotal	Other Cattle	Other Oil Palm	Total
Fertile soil	9	5	7	12	17	8
No flooding	41	39	40	12	42	38
Close to	29	28	29	26	33	29
road/house	21	28	24	50	8	25
Flatter areas						

Table 6. Reported labor (days ha^{-1}) for clearing forest and fallow by main agricultural system, Pucallpa, Peru.

	Slash-and-Burn						Other					
	Forest		Riverine		Subtotal		Cattle		Oil Palm		Total	
	For	Fal	For	Fal	For	Fal	For	Fal	For	Fal	For	Fal
Slash	20	17	22	14	21	15	18	22	12	19	20	16
Fell	30	5	28	6	29	6	22	7	18	5	27	6
Total	50	22	50	20	50	21	40	29	30	24	47	22

Table 7. Main crop sown in fields cleared from forest (n = 100) and from fallow (n = 132), by main agricultural systems, Pucallpa, Peru, in percentage of respondents.

	Slash-and-Burn						Other					
	Forest		Riverine		Subtotal		Cattle		Oil Palm		Total	
Crop sown	For	Fal	For	Fal	For	Fal	For	Fal	For	Fal	For	Fal
Rice	88	52	73	49	80	50	50	33	84	50	78	49
Maize	6	30	16	28	11	29	0	47	8	25	10	30
Cassava	3	10	0	2	1	5	25	0	0	17	3	5
Banana	3	3	11	9	8	7	25	7	8	0	9	6
Other	0	5	0	12	0	9	0	13	0	8	0	10

Table 8. Changes in land use for lands cropped to rice, maize, and cassava from 1995 to 1996, Pucallpa (% area planted in 1995).

	Planted in 1995		
Planted 1996	Rice (64 ha)	Maize (84 ha)	Cassava (57 ha)
Rice	0	1	0
Maize	7	21	0
Cassava	18	5	29
Banana	7	9	5
Pineapple	2	0	8
Pasture	4	3	4
Fallow	31	49	46
Other	31	12	8

Table 9. Repondents' (n = 131) reported crop yields (t ha^{-1}), Pucalipa, 1995-96.

	Reported range			
Crop	Low	Normal	High	Actual 1995-96
Rice	0.9	1.9	2.6	1.4
Maize	1.1	2.2	2.9	1.7
Beans	0.1	0.8	0.9	0.2

Complex Systems Tutorial

David Waltner-Toews

An Introduction to Complex Systems
David Waltner-Toews, University of Guelph

The purpose of this introduction is to lay out the basic concepts of systems thinking which are relevant to the kinds of complex situations we find in Pucallpa. Many of the examples come from physics and biology. We would encourage you to think laterally as we investigate whether or not they are applicable to the questions we wish to address.

A system in general terms, is something which has boundaries and internal mechanisms of communication and control, that is, there are feedback loops. Most scientists accept the existence of systems when they talk about organisms, which are made up of various parts which interact in loops to create a new entity. It is more difficult for many of us to imagine what kind of an entity a community or ecosystem might be. This is often because the boundaries are leakier than we are used to. This, in turn, may be a function of scale. To a bacterium, our skin looks like a vague boundary through which it can move. To us, the skin looks pretty secure as a boundary between ourselves and our environment.

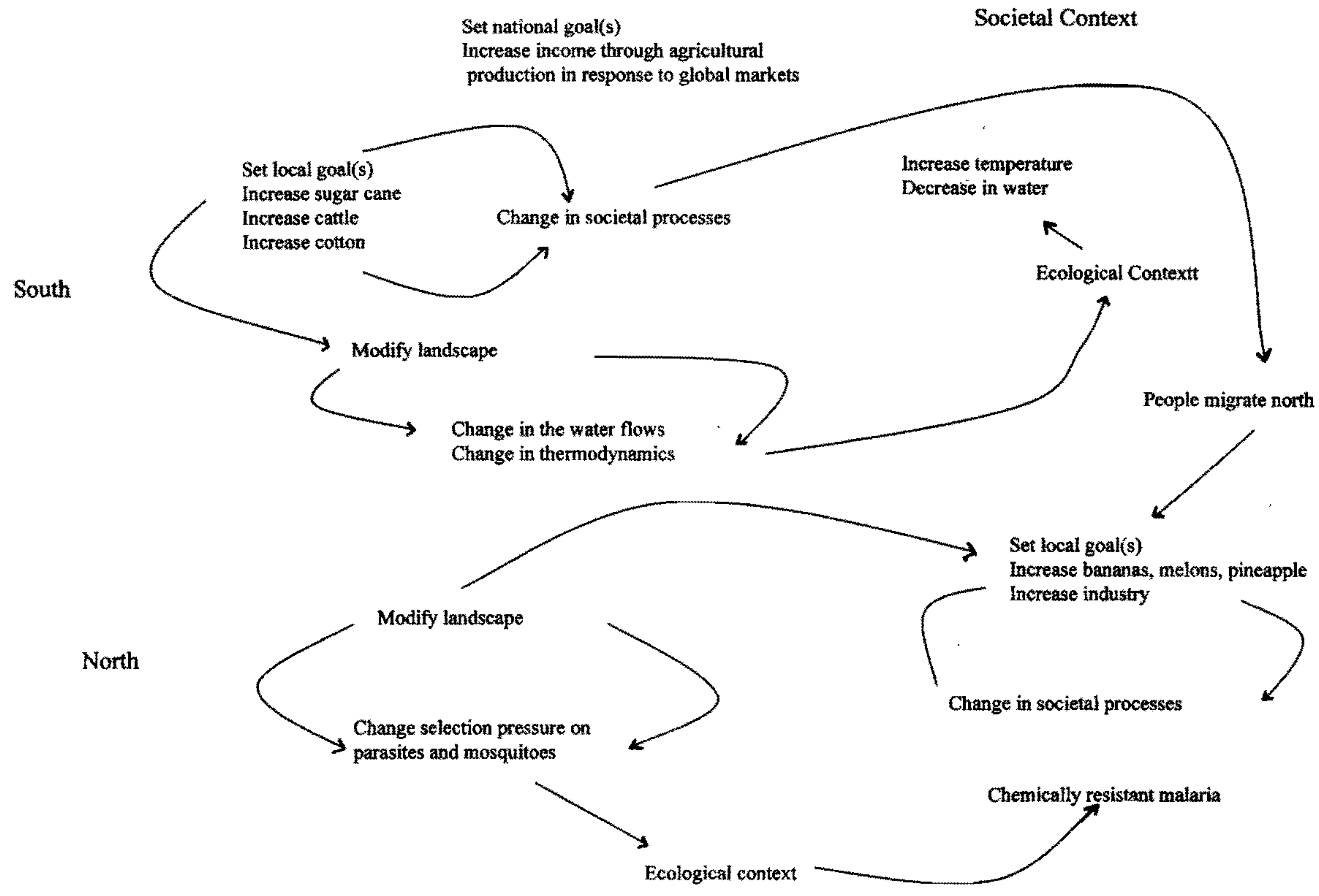
A second idea that is important particularly for complex systems, that is, systems which require more than one perspective to understand, is the notion of holarchy. A holarchy is a nested hierarchy. Each layer in this nested hierarchy is made up of things within: a cow is made up of cells, a herd is made up of cows and so on. Furthermore, each holon, or "layer" is more than simply the sum of its parts. New characteristics and behaviours emerge at each level.

Multiple scales and perspectives are important because they determine the kinds of solutions we devise. If we investigate, say plague in Tanzania, the cause of the disease in individuals is Yersinia pestis, and the treatment is tetracycline. At the household level, the cause is rats, dogs and fleas, and the treatment is rodenticides and insecticides; at the village level, we see that the plague occurs because certain kinds of habitats have been created for rats by agricultural activities. These activities make money for the men and because the society is polyganous, and the women do the housework, they get the plague. So, at each layer a different set of diagnoses and responses emerge. This is important when we consider questions of sustainability.

In Honduras (see Figure 1), national goals of increasing income through agricultural production in response to global markets led to increased production of sugar cane, cattle and cotton in the south. These activities changed the hydrological cycles and resulted in a 10 degree increase in temperature over 10 years. This, in turn, undercut productivity and led many people to move to the north, where they grew bananas, melons, and pineapples to meet the same national goals. These products require a lot of pesticides to grow ,which led to an increase in pesticide resistant mosquitoes carrying malaria. The people from the south had not previously experienced malaria because the mosquitoes had not survived the temperature increases in the south.

So what is the cause of malaria in northern Honduras? What is an appropriate policy response? Complex systems are one way to look at these dynamics that might help us come up with answers to these questions.

Figure 1: Conflicting Goals and Cross-scale Interactions in Honduras



Complex Systems Tutorial

Some Notes on: The Ecosystem Approach, Ecosystems as Complex Systems

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with material from Dr. Eric Schneider, Prof. Henry Regier, Dr. Stephen Woodley, Prof. George Francis, Prof. Scott Slocombe, Dr. Christian Pupp and the Students of the Huron Natural Area[1] Working Group

The essentials of an* ecosystem approach *at a glance

- Living systems are self-organizing. Our challenge is to promote this capability to self-organize, while still procuring what we need from the biosphere.

- Ecosystem analysis is done in the context of nested holons, that is a hierarchically organized system description of the area of study. Careful attention must be given to scale and extent of analysis at each hierarchical level. The behaviour of a system (holon) is due to the interactions of its components (also holons) in the context of the wider system (another holon) it is part of. Focus on one level, or by one discipline, cannot adequately describe these interactions between hierarchical levels and this is crucial for understanding self-organizing entities.

- Both bio-physical and human cultural perspectives must be brought to bear as part of ecosystem analysis. Each of these perspectives will generate a different hierarchical representation of the ecosystem. The challenge is to integrate these perspectives to give an understanding of the whole

- Ecosystem dynamics are complex, that is they are not deterministic, have a degree of unpredictability, exhibit phases of rapid change and even catastrophic change, are continually evolving and going through a birth, growth, death, renewal process (figure ∞) at different temporal and spatial scales.

- Understanding ecosystem dynamics requires investigating the spatial, temporal, thermodynamic, information and cultural aspects of living systems.

- Synergistic effects and emergence (and hence surprise) are normal in self-organizing systems.

- The ecosystem approach cannot be about quantitative prediction alone but also must be about qualitative understanding. The ability to predict in many ecological situations is, in principle, quite limited. The best we can expect is a general qualitative sense, based on our knowledge of interconnections and past history. In this context management must be both anticipatory and adaptive.

---

[1]Ryan Metcalfe, Steve Diggon, Carl Burgess, Robin Green, Marnie Eggen, Brian McHattie, Mark Conrad, Clint Johnson are undergraduate ERS students who have worked on developing a framework for monitoring ecosystem integrity in the Huron Natural Area.

- Ecosystem management is an oxymoron. It is our interactions with ecosystems which need management.

- The ecosystem approach is both analytic and synthetic. It involves analysis of living systems by disciplinary science. But understanding comes from synthesising together the different perspectives gained from disciplinary science.

- Discussions of ecological integrity by necessity involve making value laden judgments and hence involve ethics and politics as well as science.

The core tenet of the notion of sustainability is that humans are an integral part of the ecological systems which make up the biosphere. We cannot live apart from the biosphere but only as a part of it. Sustainable development, therefore, is development which fosters ecological integrity. Recognizing this, society has mandated, through various policy statements and legislation (the Great Lakes Water Quality Agreement, 1978, the Canada Park Service Act, 1988, the Montana Environmental Protection Act, 1992, Environment Canada's mission statement, 1992) the preservation, maintenance, promotion, protection, and restoration of ecological integrity.

This is well and good. But it does not help us unless we can operationalize the notion of integrity, and how to report on it. This is the quest that a number of us have been working on for the last fifteen years. This paper is a brief synopsis of what we have learnt. It is a meant to stimulate discussion and further reading of the literature. The essential issues to be covered are: a) what is meant by ecological integrity, b) how do we evaluate it and c) what are the implications for Monitoring.

Complex Systems Thinking

A new understanding of ecosystems is emerging, and this understanding is the basis for discussing integrity. This new understanding comes from a group of thinkers who suggest that an "ecosystem approach" should be based on the notions of *complex systems theory*, the grandchild of von Bertalanffy's general systems theory[2]. The vision of an ecosystem, that the "new science" of complex systems theory provides, is quite different from that of a traditional Newtonian mechanistic world view. It is a vision of ecosystems as dynamic, constantly evolving systems which are not deterministic, but rather to a degree unpredictable. Change in such systems can be smooth or just as likely, sudden and surprising. Such systems can exhibit phases of rapid change, and even the extreme of catastrophic change is not abnormal. Left to their own devices, ecosystems are self-organizing, that is they will look after themselves.

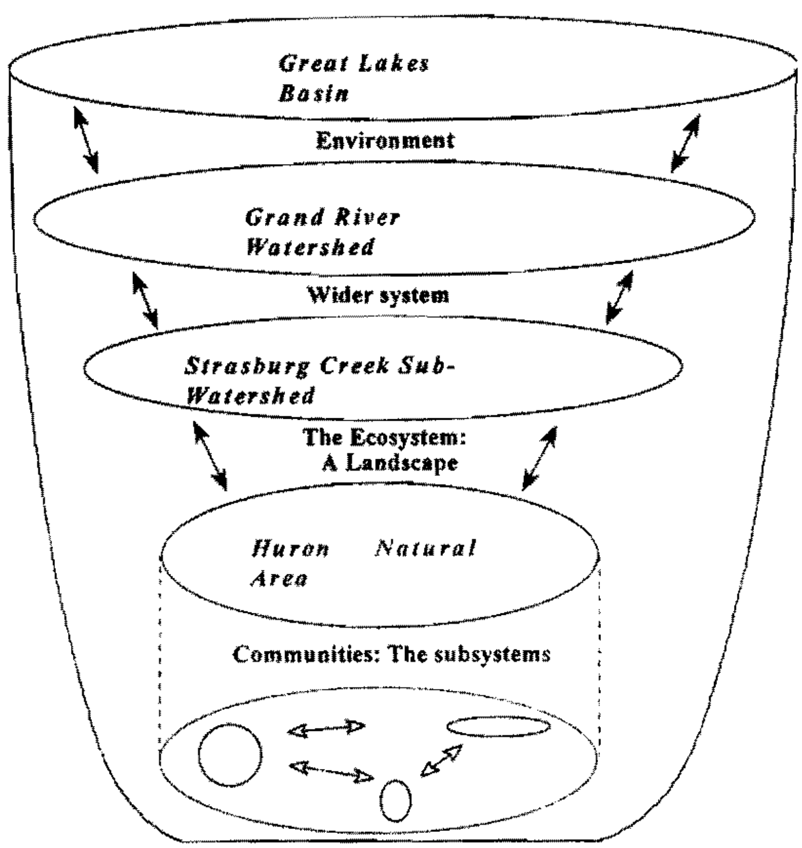
Table 1: An analysis of the ecological health of National Parks involves an evaluation for every hierarchical level: (Different measures are required for different levels.) (Adapted from Woodley 1993)

LEVEL	EXAMPLE HEALTH MEASURES
LANDSCAPE	Patchiness,
ECOSYSTEM	Leakiness, Total energy use, Cycling.
COMMUNITY	Biomass, Crown Closure
POPULATION	Numbers, genetic diversity, reproduction rates
INDIVIDUAL	Health

[2]Kay & Schneider, Schneider & Kay 1994, Allen and Hoekstra 1992

Figure 1: Nested Holons (Hierarchy Theory)

The behaviour of a system (holon) is due to the interactions of its components (also holons) in the context of the wider system (another holon) it is part of. We can only understand systems from a hierarchical perspective, that is as nested holons. Generally five levels of description are required. The Huron Natural Area nested Holons are seen below:



There are a number of important lessons to be learnt from the study of complex systems. First, such systems can only be understood from a *hierarchical perspective.*[3] Neither a reductionist nor holistic approach is sufficient. One must look at the system as a whole and as something composed of subsystems and their components. (See Figure 1 and Table 1) One must also look at the system in the context of its being a subsystem of a bigger system which is in turn part of a wider environment. So to study a population in ecology without reference to the individuals that make it up, the community it belongs to, and the environment it lives in, is not sufficient. This is not to say that population ecology is not useful. It is just not sufficient to explain ecological phenomena. Self-organization of complex systems, including ecosystems, can only be understood in the context of what makes them up and the environment in which they must function.

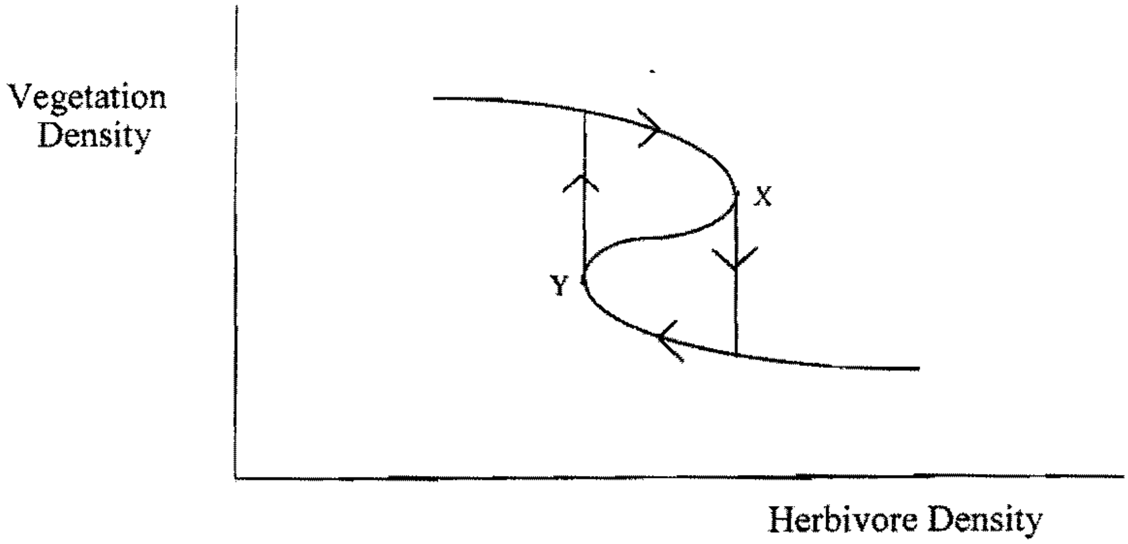
Another property of these systems is that everything is connected (at least weakly) to everything else. But no scientist can look at everything at once. So any analyst must make decisions about what to include and what to leave out of the system to be studied. Scale and

[3]Woodley, 1993 T.F.H. Allen, 1982, 1992, 1993, A. King 1993, F. Günther and C. Folke, 1993

extent and the hierarchical units of study must be selected. These decisions, while done in a systematic and consistent way, are necessarily subjective, reflecting the viewpoint of the analyst about which connections are important to the study at hand, and which can be ignored. So, because of their very nature, the notion of a pristine objective scientific observer is not applicable to the study of self-organizing systems. This has significant implications for ecosystem classification and boundary selection.

Figure 2: A simple example of catastrophes in ecology

As the herbivore population increases, the vegetation decreases (more is eaten). The system moves along the upper solid line (attractor). Eventually a point (X) is reached where the vegetation crashes (the system becomes unstable) because of overgrazing. As the vegetation regrows the herbivore population drops off sharply (the lower solid line, another attractor) until a second point (Y) is reached (the system becomes unstable again) and a vegetation bloom occurs. The vegetation crash and bloom are *catastrophes* in the mathematical sense of the word. X and Y are known as *critical thresholds*.



Complex systems exhibit emergent dynamic behaviours. *Catastrophe theory*[4] describes one class of surprising dynamics of these systems. It predicts that systems will undergo dramatic, sudden changes in a discontinuous way. For example, in studies of acidifying lakes, investigators noticed in the 1970s that even in cases where sensitive water bodies were subject to a continuing rain of sulphates and nitrates from the atmosphere, the water pH did not change very much for quite a long time. But then, rather suddenly, the pH would drop sharply. The explanation is that until the buffering capacity of a lake is used up, the pH changes little. A contributing factor is spring snow melt, which causes a sudden flush of sulphates and nitrates stored over the winter. The example often cited is Big Moose Lake, N.Y., where pH remained almost constant in the period 1900-1960, and then fell precipitously [5]

[4] R. Thom, 1969;K. Huseyin, 1977
[5] Stigliani, 1988;

That ecosystems exhibit catastrophic behaviour has several important implications:

- Ecosystems can have several stable states (i.e. multiple attractors)
- Sudden change is normal in an ecosystem. (Fire, pest outbreak, the dropping of leaves....)
- Knowing the current value of environmental variables is not sufficient to know the state of the ecosystem, its history must also be known (that is you must know which attractor it is on.)
- Suppression of these sudden changes only sets the system up for bigger changes later.

Another example, which gives serious pause for thought, is that there is recent evidence for a "flip-flop" end to the last Ice Age in Greenland, with "a double shift from glacial to interglacial conditions over an astonishingly quick 3-5 years" about 18,000 years ago ; the temperature changed by about 7° C during these shifts[6].

Furthermore, at the point where a system undergoes a "catastrophic" change, there may be several possible distinct changes which can occur. Which one will actually happen is not always predictable. The insight from catastrophe theory is that the world is not a place where change always happens in a continuous and deterministic way.

The choice of the name, catastrophe theory, is unfortunate as it denotes abnormal nasty events. What we have come to realize is that such events are normal and necessary for the continued smooth functioning of many systems. For example our heartbeat is a catastrophic event, as is the emptying of our bladder. They are discontinuous events which occur suddenly and are necessary for our continued survival. Over the last decade students of ecosystems have come to realize that such behaviour is not only normal for ecosystems, but necessary for their well being (for example fire and pest outbreaks in forested ecosystems).[7]

Classical ideas of ecosystem development are based on succession, which ultimately leads to a steady-state condition: climax vegetation. Holling[8], building on the ecological insight gained from catastrophe theory, has extended this conceptual framework of ecosystem development in two ways :

1. Succession is only one phase of the *figure-eight (∞)* pattern.
2. Ecosystems are spatially and temporally *lumpy*; uniform ecosystems exist only in monocultures. Patchiness is an essential characteristic of an ecosystem that has integrity.

These two ideas are connected in the following way. Succession (initially, a relatively fast process) is the upward loop in figure 3 extending from **Exploitation** to **Conservation** (the climax state). In this latter "mature" state, most of the nutrients and energy are locked up in the biomass, and the system gradually becomes brittle. Key structural parts become risk prone, waiting for an accident to happen through fire, wind-storms, pests and senescence (the downward segment in the figure, i.e., from **Conservation** to **Release**). This latter relatively fast process generally occurs in patches, releasing nutrients and energy locally and ultimately permitting the cycle to move on in the figure eight from **Release** to **Reorganization**. Finally, the loop is closed through **Exploitation** (succession) back to **Conservation**. Lumpiness is an essential part of the figure-eight model, and indeed of nature itself. The processes take place over a range of space and intergenerational time scales (from days and mm. to centuries and thousands of square Km.). Understanding ecological integrity requires understanding these ∞ patterns and the associated lumpiness.

[6]Alley,et al., 1993; Fairbank, 1993
[7] Kay, 1991
[8]C.S. Holling, 1986,1992

Another characteristic of an ecosystem with strong integrity is the existence of an information library, mainly the species and their genes. Genes contain the historical record of previously successful self-organization. They constraining the self-organization of an ecosystem to those options which have a high probability of success (Kay, 1984). Referring to figure 3, the system information library is of most importance at the point of exit from the Figure ∞ to the left of the figure. This is where a flip into a greatly modified ecosystem is most likely. This point, the transition to the exploitation phase, is when the ecosystem is, in effect, reset. What the ecosystem is reset to, is a function of the environmental context and the information available at the time of reset. This is the moment when **biodiversity** is most important.

Holling has extended these ideas even further. Recognizing that there are nested cycles of both time and space scales involved in ecosystem development, Holling argues that for each scale, only small numbers of processes and species predominate. Thus a reasonable picture of the functioning of the system **at that level** can be obtained by concentrating on these most important processes and species. However, interactions between processes operating at different levels (i.e., different time and space scales) do occur and furthermore are non-linear, with the possibility of flip-flops. Thus the behaviour of the system at higher or lower levels of aggregation cannot be easily ascertained from that at the time and/or space scales being investigated. Holling has supported these ideas with a cross-scale analysis of animal body mass, which shows discontinuities across landscapes.

Another set of insights into complex systems comes from *self-organization theory* and particularly, *nonequilibrium thermodynamics*. Prigogine[9] showed that spontaneous coherent behaviour and organization (i.e. tornadoes, vortices in fluids, lasers) can occur and is completely consistent with thermodynamics. The key to understanding such phenomena is to realize that these are *open systems* with a flow of high quality energy. In these circumstances, coherent behaviour appears in systems almost magically. Prigogine showed that this occurs because the system reaches a catastrophe threshold and flips into a new coherent behavioral state.

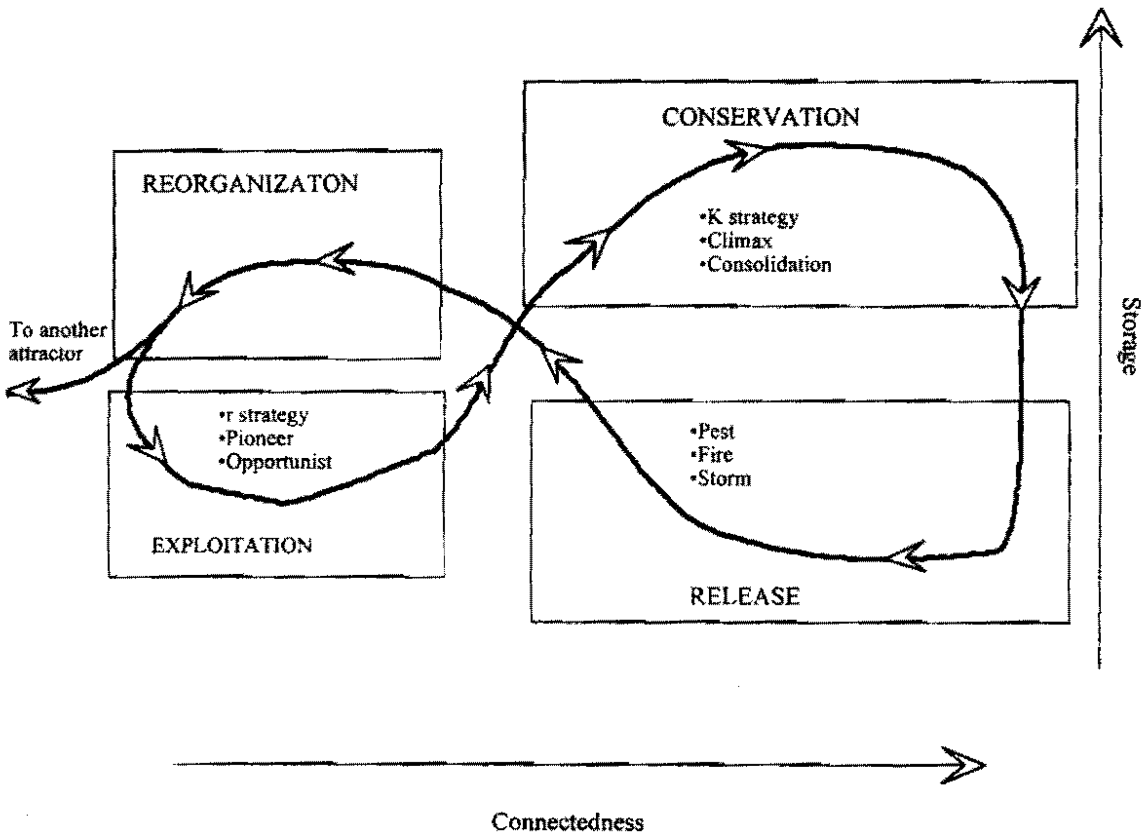
In examining the energetics of open systems Kay and Schneider[10] have taken Prigogine's work one step further. They are interested in open systems with high quality energy pumped into them and their consequent movement away from equilibrium. Systems resist this movement away from equilibrium. If new kinetic and dynamic pathways for dissipation are available, the open system will respond with the spontaneous emergence of organized behavior that uses high quality energy to maintain its structure, and dissipates high quality energy in its movement away from equilibrium. The more high quality energy pumped into a system the more organization can emerge to dissipate the energy. Again, the emergence of organized behavior, (and even life) in systems, is now expected according to modern thermodynamics. This self-organization is characterized by abrupt changes which represent a new set of interactions and activities by components and the whole system. The form of expression this self-organization takes is not predictable. This is because the very process of self-organization is via catastrophic change (in the catastrophe theory sense) and flips into new regimes.

[9]Nicolis and Prigogine. 1977, 1989

[10]Schneider and Kay, 1994a &b.

Figure 3: The Holling "figure-eight ( )" model of an ecosystem. The cycle reflects changes in two attributes: (1) y-axis; the amount of accumulated capital (nutrients, carbon) stored in variables that are the dominant variables at the moment; and (2), the x-axis; the degree of connectedness among variables. The exit from the cycle at the left of the figure indicates the stage where a flip into a greatly modified ecosystem is most likely. It is at this juncture that the ecosystem's information library (stored mainly in the species and their genes) steers it around the figure .

Holling's *four box* or *figure 8* model of ecosystem dynamics



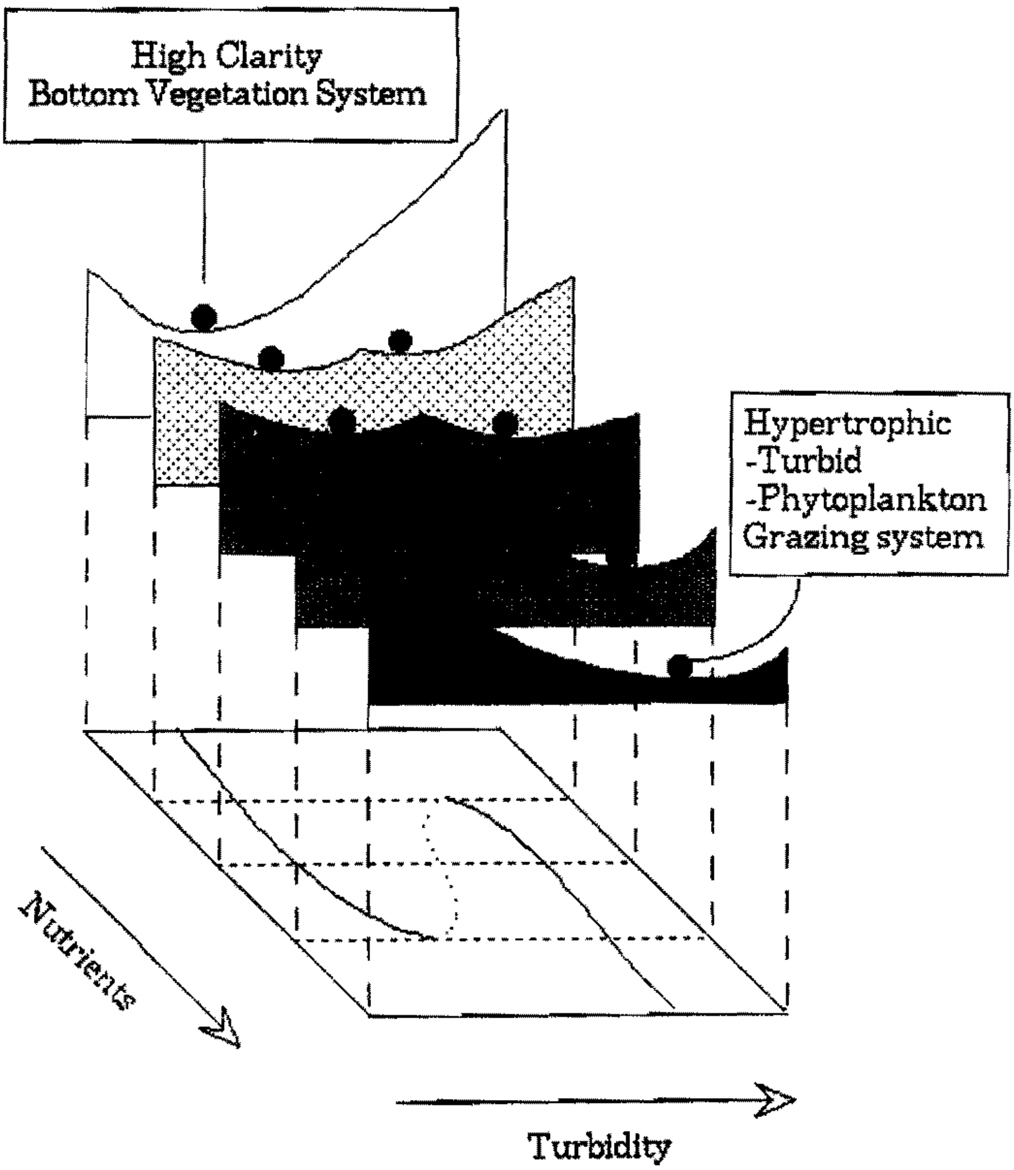
Holling's ideas reinforce the notion of ecosystems as dynamic structures that:

- are continuously going through a process of re-organization and renewal;
- must be dealt with at different temporal and spatial scales using different tools;
- regularly exhibit catastrophic behaviour with several attractors;
- from time to time are reset to develop as a new ecosystem organization.

This is a much richer vision of ecosystem behaviour than the traditional model of succession to a single climax community. It eliminates the notion that ecosystem management is about maintaining an ecosystem in a single, stable, stationary state.

Figure 4: Example of Multiple attractors
Benthic vs. Pelagic shallow lake ecosystems[11]

Two different states for shallow lakes have been identified. In the benthic state, a high water clarity bottom vegetation ecosystem exists. As nutrient loading increases the turbidity in the water, the ecosystem hits a catastrophe threshold and flips into a hypertrophic, turbid, phytoplankton pelagic ecosystem. Lakes which flip between these states on a regular basis have been found. (Lake Ontario appears to be currently in the midst of such a flip, from pelagic to benthic.) In some lakes, the spring run off (nutrient loading) determines which state the ecosystem will be in for the summer. This is an example of a bifurcation in an ecosystem's behaviour as it hits the reset point for the seasonal figure .



[11] Taken from M. Scheffer et al.

The vortex which forms in a bathtub, is an example of this behaviour. This type of vortex appears almost by magic. It drains the water more quickly. The more water there is to begin with (bigger gradient, more exergy) the faster the vortex drains the water. Such self-organizing phenomena (like life) is no longer considered an enigma in the sense that it runs counter to the laws of thermodynamics. Everything isn't running down, rather the spontaneous emergence of organized systems is to be expected. Furthermore these systems tend to get better and better at grabbing resources and utilizing them to build more structure.

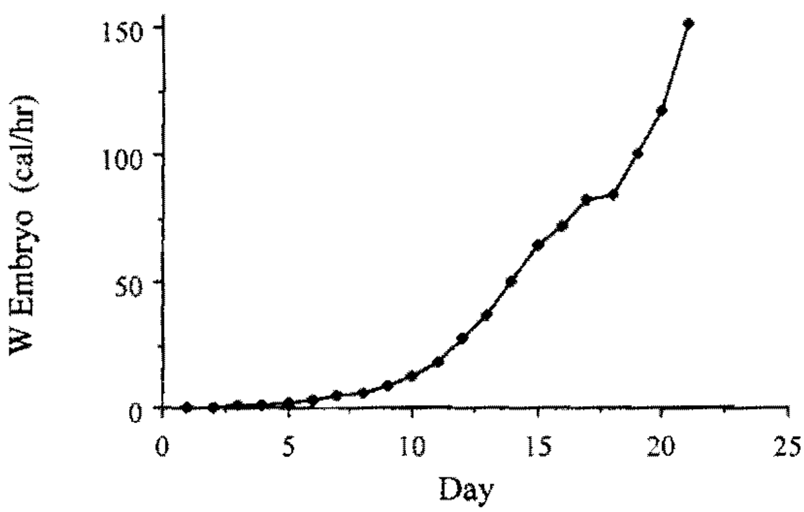
Ecosystems as self-organizing entities

The theory of non-equilibrium thermodynamics suggests that the self-organization process in ecosystems proceeds in a way that: a) captures more resources (exergy and material); b) makes more effective use of the resources; c) builds more structure; d) enhances survivability. These seem to be the basic rules of the game (self-organization) in ecosystems.

Figure 5: Life as a Self-organizing System

As living systems develop, the direction of this development improves their ability to survive and utilize energy. Consider the growth of a chicken embryo as in the following graph. The point is that as the embryo develops, it use more energy (W), that is it gets better at extracting energy from its fixed source, the yoke.

Dissipation rate for a chicken embryo



Data from Briedis and Seagrave, 1984

We see the same phenomena in ecosystems. As ecosystems develop, that is become better organized, they also become more effective at capturing solar energy and extracting the exergy from it. This can be measured by flying over a terrestrial ecosystem and measuring its surface temperature. The surface temperature measures the quality of the energy, after the ecosystem has used it and is finished with it. The **cooler the temperature**, the more thoroughly the ecosystem has utilized the energy. This can also be used to measure the effectiveness with which the ecosystem utilizes the energy.

Using data collected by Luvall and Holbo for the H. J. Andrews experimental forest (temperate rainforest, Douglas Fir) we can see this phenomena. The following data was collected and is organized from least developed to most developed ecosystem. It clearly demonstrates that we can measure ecosystem organization using energy balance techniques and that more developed ecosystems are better at utilizing the available energy.

	Quarry	Clearcut	Douglas Fir Plantation (30 years old)	Natural Forest regrowth (30 years old)	Douglas Fir Forest (400 year old)
Temperature (°C)	50.7	51.8	29.9	29.4	24.7
Effectivenes s (%)	62	65	85	86	90

Systems that exhibit self-organization exist in an energetic window where they get enough energy, but not too much. If the they do not get sufficient energy of high enough quality (beyond a minimum threshold level), organized structures cannot be supported and self-organization does not occur. If too much energy is supplied, chaos ensues in the system, as the energy overwhelms the dissipative ability of the organized structures and they fall apart. So self-organizing systems exist in a middle ground of enough, but not too much.[12] Furthermore, these systems do not maximize or minimize their functioning. Rather their functioning represents an optimum, a trade-off among all the forces acting on them. If there is too much development of any one type of structure, the system becomes overextended and brittle. If a structure is not sufficiently developed to take full advantage of the available energy and resources, then some other more optimal (i.e. better adapted) structure will displace it. Self-organization in ecosystems is a dynamic ongoing balancing act striving for the middle ground. The only static equilibrium stable state for living systems is death.

Management goals that involve maintaining some fixed state in an ecosystem or maximizing some function (biomass, productivity, number of species) or minimizing (pest outbreak, fire) will always lead to disaster no matter how well meaning they are. We must instead recognize that ecosystems represent a balance, an optimum point of operation, and this balancing is constantly changing to suit a changing environment. *Management must focus on facilitating and directing change, not attaining and maintaining some fixed state for all time.* We must manage our behaviour so that it enhances the organization of the ecosystems which we are all part of.

Understanding ecosystems as self-organizing entities requires a hierarchical perspective with careful attention to scale and extent. We must examine the spatial, temporal, thermodynamic and information aspects (dynamics) of these systems. This must be done in the context of behaviour which is both emergent and catastrophic. In other words we must recognize that ecosystems are dynamic, not deterministic, have a degree of unpredictability and will exhibit phases of rapid change.

But this is not to say that ecosystem behaviour is chaotic or random and haphazard. On the contrary, ecosystem behaviour and development is like a large musical piece such as a symphony, which is also dynamic and not predictable and yet has a sense of flow, of connection between what has played and what is still to play, the repetition of recognizable themes and a general sense of orderly progression. In pieces such as symphonies or suites we

[12]R.E. Ulanowicz, in press

THREE ASPECTS OF ECOSYSTEM INTEGRITY:

1) Ecosystem Health: Current well being in **normal environmental** conditions

2) Ability to deal with stress, that is a **changing environment**.

3) Ability to continue the process of self-organization. **Change from within.**

know the stages (allegro, adagio, etc.) that the piece will progress through, even though we don't know the details of the piece. The same is true of ecosystems, some behave in a very ordered way as does a Baroque suite, and others are full of improvisation as in modern jazz. And yet we know the difference between music and random collections of noise. Our challenge is to understand the rules of composition and the limitations and directions they place on the organization process, as well as what makes for the ecological equivalent of a musical masterpiece which stands up to the test of time.

Ecosystem Integrity

Our sense of the ecosystem as a whole, that is its *Integrity*, has to do with its ability to maintain its organization and to continue its process of self-organization. For an ecosystem, integrity encompasses three major ecosystem organizational facets. **Ecosystem health**, the ability to maintain normal operations under normal environmental conditions, is the first requisite for ecosystem integrity. But it alone is not sufficient. To have integrity, an ecosystem must also be able to cope with changes (which can be catastrophic) in environmental conditions; that is, it must be able to **cope with stress.** As well, an ecosystem which has integrity, must be able to **continue the process of self-organization** on an ongoing basis. It must be able to continue to evolve, develop, and proceed with the birth, growth, death and renewal cycle (i.e. Holling's Figure ∞). It is these latter two facets of ecosystem integrity that differentiate it from the notion of ecosystem health.

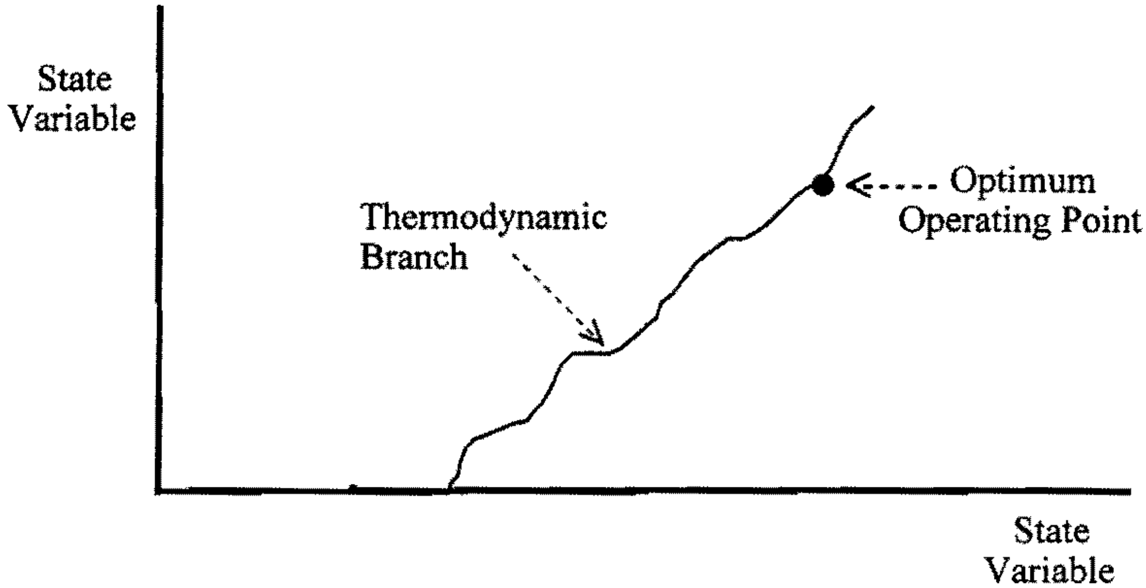
This understanding of the behaviour of complex self-organizing systems provides a framework for the investigation of environmentally induced changes in ecosystem organization and integrity.[13] It establishes that ecosystems can respond to changes in the environment in five qualitatively different ways:

- The system can continue to operate as before, even though its operations may be initially and temporarily unsettled. (Figure 6)
- The system can operate at a different level using the same structures it originally had (Figure 7).
- Some new structures can emerge in the system that replace or augment existing structures (Figure 8)
- A new ecosystem, made up of quite different structures, can emerge. (Figure 9)
- The final, and very rare possibility, is that the ecosystem can collapse completely and no regeneration occurs.

This enumeration of possible ecosystem responses to environmental change is far richer than the simple classical notion, which holds that stress temporarily displaces an ecosystem from its climax community, to which it eventually returns. In fact, an ecosystem has no inherent single preferred state for which it should be managed.

[13]Kay, 1991

Figure 6: The process of self-organization in ecosystems:
Development is characterized by phases of rapid organization to a steady-state level followed by a period during which the system maintains itself at the new steady state. The organization of the system is not a smooth process but rather proceeds in spurts. These spurts are a sudden acceleration in the change in the state of the system. The overall direction of development is one which satisfies the necessities of increasing energy degradation while enhancing survivability. An ecosystem develops along a *Thermodynamic Branch* (a path in state space) until it reaches an *Optimum Operating Point.*. This is a point in state space where the self-organizing forces are balanced by the disorganizing forces of external environmental change. (This is an simplification of the more complex process described by Holling's figure).



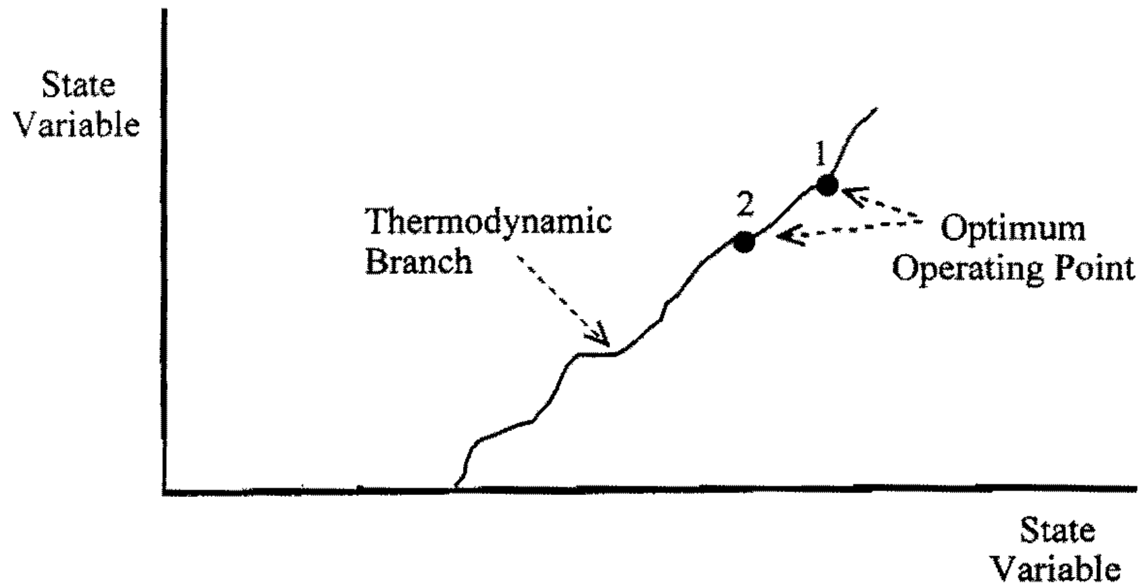


Figure 7: The environmental change causes the ecosystem to move from its original optimum operating point (1) to a new optimum operating point (2). An example of this would be a stress which causes an ecosystem to return to an earlier successional stage. The practice of spraying the end product of the secondary treatment of municipal waste water on terrestrial ecosystems is such a stress. Pine forests subjected to such spraying are shifted back to an old field community (i.e. the developmental stage prior to a forest)

While this list identifies the ways in which an ecosystem might re-organize in the face of environmental change, it does not indicate which re-organization constitutes a loss of integrity. It could be argued (and often is) that any environmental change that permanently alters the normal operations of an ecosystem affects its integrity. Ecosystem integrity would then be defined as the ability to absorb environmental change without any permanent ecosystem change. Thus the final three distinct ecosystem responses, in the list, would constitute a loss of integrity, even though all are responses in which the ecosystem reorganizes itself to mitigate the environmental change. However, the reorganized ecosystem is usually just as healthy as the original, even though it may be different. There is no scientific reason that an existing ecosystem should be the only one to have integrity in a situation, just because of its primacy.

At the other extreme, it could also be argued that any ecosystem that can maintain itself without collapsing has integrity. Utter collapses have been rare, desertification being one of the few examples. This definition would encompass almost all ecosystems, including ones whose organization has changed radically in response to major stress.

Neither of these definitions of integrity is operationally useful. The definition which accepts only temporary change is too restrictive in most situations, and reflects a desire to preserve the world as it is currently. This denies the fundamental dynamic nature of ecosystems and leads to disastrous mismanagement (e.g. the complete suppression of forest fires, which eventually results in catastrophic conflagrations). But the latter definition, which accepts all responses except collapse, does not help managers because it restricts loss of integrity to a situation that rarely occurs and that is clearly undesirable. Hence this definition would be trivial.

In between these two extremes of definition lies a third option, which holds that some changes in ecosystems are undesirable, and therefore represent a loss of integrity. This option promises to be the most useful but it embraces many possibilities and requires difficult choices. In particular it requires the value-laden selection of criteria for determining which changes are desirable and which are not. The science of ecology can, in principle, inform us about the kind of ecosystem response or reorganization to expect in a given situation. It does not provide us with a scientific basis for deciding that one change is better than another, except possibly in the two extreme cases just discussed.

The insight into ecological integrity gained from complex systems theory is that the physical and biological sciences can describe and, even to a limited extent, predict human-induced changes in the biosphere, but they alone cannot determine which changes are acceptable. Ultimately, any evaluation of the ecological acceptability of a human activity, will depend on value judgments about whether the resulting changes in the affected ecosystem are acceptable to the human participants.

Evaluating Integrity and Monitoring

We have less than ten years experience at undertaking evaluations of ecological integrity. There are many problems still to be worked out and many issues, both theoretical and methodological that require further research. So it is not yet possible to present a coherent body of knowledge about ecological integrity and hence methodology for monitoring. Several efforts have been made to pull together what we do know[14] and I recommend these for further exploration.

[14]Edwards & Regier, 1990; Costanza, Norton & Haskell; 1992; Woodley, Kay and Francis, 1993; Slocombe.

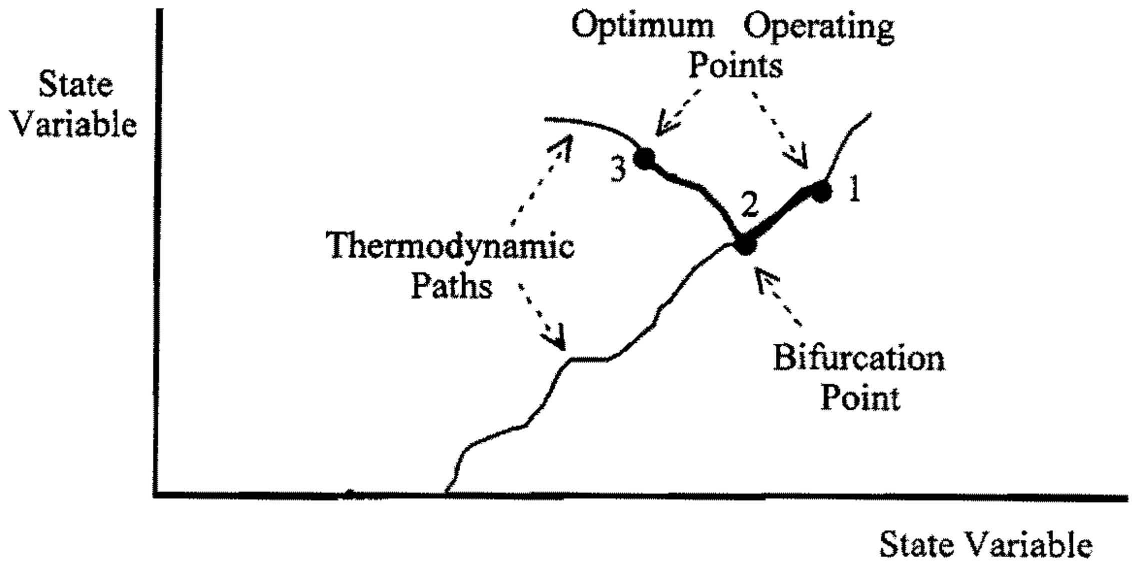


Figure 8: In response to changing environmental conditions the system moves away from the original optimum operating point (1) through a bifurcation point (2) and onto a new path and then to a new optimum operating point (3). An example of this case is the switch from a white spruce community to a black spruce community when the former is subjected to a sharp reduction in nutrient availability. In these forested taiga ecosystems, black spruce are better suited to low nutrient situations and once established tend to exclude white spruce by maintaining the low nutrient situation. The white spruce is not able to reassert itself once displaced.

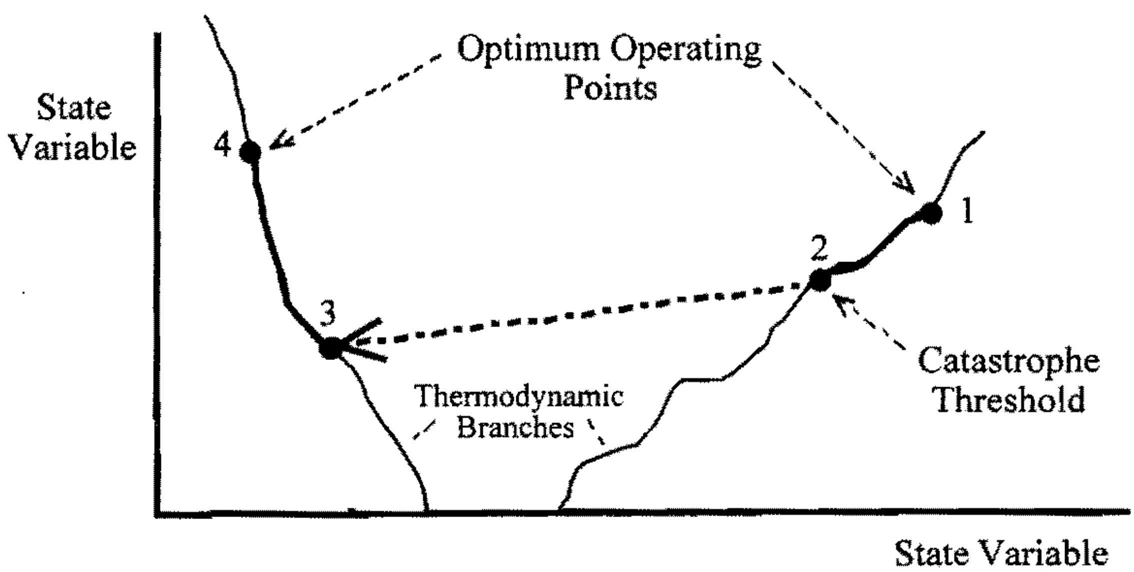


Figure 9: The environmental change drives the ecosystem from its original optimum operating point (1) through a catastrophe threshold (2) to a new thermodynamic branch at (3) and eventually to a new optimum operating point (4). An example is the elimination of fish in lakes caused by acid rain. Another example of this is the switch between pelagic and benthic ecosystems in shallow lakes as discussed earlier.

In the final analysis, to define ecological integrity is to define a set of ecological characteristics to be monitored for change beyond specific values. To operationalize the notion of integrity requires the development of a monitoring framework and its associated measures and indicators. There are three distinct issues to be dealt with in developing a monitoring scheme for ecological integrity. First the changes in organization, to be associated with changes in ecological integrity, must be identified. Then comes the scientific and technical problem of how to quantify these changes. What needs to be measured and how is it best done? These are scientific and technical issues we are all struggling with. Once measurements have been decided upon, the issue of evaluation becomes paramount. For what values of the measures will integrity be deemed to have been lost? Who will make this decision and who will act on it? To answer the first and the last of these three questions, requires that the understanding of physical and biological scientists be combined with the concerns of society as voiced by elected officials, policy makers, public interest groups, and others. Only when this combination occurs, will it be reasonable to expect ecological integrity to result from our stewardship of the biosphere.

The process of developing a monitoring framework must start by identifying the users of the information gained from the monitoring. What information do they need, and in what form must it be presented to be usable? With this established, a system identification exercise is conducted so as to resolve such issues as what hierarchical levels will be focused on, what temporal and spatial scales will be covered, and what processes need to be monitored.

Measures for several different hierarchical levels and scales will be needed (Shackell & Freedman, King). The measures will be rooted in the bioregion and social issues in question (Keddy et al). Also, measures drawn from a number of different theoretical perspectives (e.g. landscape ecology, self-organization theory, population biology, etc.) will be required for a complete picture (Karr). Some measures will monitor the general condition of the ecosystem and its environment. Others will focus on specific known threats and the system's response to these threats. (Marshall et al, Woodley). Some will assess damage while others will serve as early warning alarms.

Clearly a variety of measures are necessary to adequately monitor ecological integrity. King points out that measures must not be over-integrated as this will result in the loss of valuable information. Steedman and Haider, and Keddy et al suggest methods for developing monitoring schemes and indicators. Woodley, Shackell and Freedman, Marshall et al., and Munn all discuss criteria for monitoring programs and indicators of ecological integrity. The work of Scheifer et al (1988) and Harris et al (1987) also provide guidelines for selecting measures. Recently the International Joint Commission has published a framework for developing indicators of ecosystem health for the Great Lakes Region (International Joint Commission, 1991).

Having completed the process of identifying the changes to be monitored and the measure thereof, we still face formidable technical and scientific problems. Ecology is still a young science and many methodological issues remain to be resolved. Karr points out, for example, that there is a tendency to take averages as the signal and variability in what is measured as noise. Both he and Woodley point out that the variability is often, in fact, the signal. But how to measure this?

The next step is development of evaluation criteria. Steedman and Haider propose a process for developing criteria in general.

Examples of monitoring schemes and specific indicators of integrity are presented in our book[15]; for bottom sediments (Reynoldson and Zarrell), for wetlands (Keddy et al.), for the Atlantic ecozone (Schackell and Freeman), for stream ecosystems (Karr), and for national parks (Woodley). Kay and Schneider (1993) discusses measures of ecosystem integrity based on foodweb analysis. All of these discussions of ecological integrity are rooted in a specific context.

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[15] Woodley, Kay, Francis, 1993

Complex systems theory and traditional science can help us describe and understand changes in ecological systems. Systems theory can help us focus on issues of importance, vis a vis integrity. However they alone cannot determine which ecological changes constitute a loss of integrity. *When we define ecological integrity we are undertaking to integrate everything we know about an ecological system and where we want it to be. This integration, to be complete, must include the sum total of human preferences and concerns about the system. We must find paths for ecosystem development which assure our species survival both in the short and long term. Such paths will balance the needs of other species with our own, so as to maintain a biosphere in which humans have a sustainable niche.*

We are developing a framework for doing just this. The first step is an evaluation of ecological integrity using the steps outlined in appendix 1. An example of the application of this methodology to a relatively simple example is contained in appendix 2. Figure 10 contains a different representation of the same methodology with the addition of explicit decision making and management components. This figure clearly differentiates between four distinct phases in the process

The left box which is about undertaking a *system study* to understand the current status of the ecosystem. This analysis explicitly describes the ecosystem using the notions of complex system thinking. As such it is a marriage of systems identification and scientific analysis. The former involves identifying the nested holons to be studied by bringing together all the stakeholders and experts in order to define the proper (not correct) focus (i.e. scale, extent, hierarchy etc.) for the study. This exercise can be facilitated using a methodology such as Checkland's *Soft Systems Approach.* The latter involves understanding the ecosystem in terms of the attractors available to it, its behaviour about these attractors (Holling's Figure ∞ for example) and particularly what is likely to precipitate flips between the attractors. Particular attention needs to be paid to the feedbacks, that is the self-organizing processes, which are operating to promote the attractors. This activity represents an effort to integrate the best scientific understanding we have about the ecosystem. Such an understanding depends on the availability of historical and current information about the ecosystem under study. Without adequate long term ecosystem research and monitoring, as discussed above, the ability to successfully complete this phase is compromised.

The box on the right is the input from the *political process* in society. In our work we have answered this question by drawing on vision statements and policy documents for the area being examined.[16]

The diamond represents the coming together of what has been identified as being possible with what we desire and need. This is the point where science and socio-political issues are brought together to define what constitutes a loss of ecological integrity. This is the business of post-normal science[17]. Again this is a political process that involves real world tradeoffs. This step consists of identifying inconsistencies between what society wants to do and what is ecologically possible.

The bottom box is about *goverance, monitoring* and *ecological management,* that is management of our influence on ecosystems. Ecological management is about identifying the influences we have on the feedbacks which promote the ecosystem's attractors. We must decide which feedback and self-organizing processes to encourage and which to discourage by altering our influence as is appropriate.

A simple example is in order. In the Huron Natural Area (See Appendix 2) a **closed soft maple swamp** (current attractor) in a wetland community could be pulled toward different attractors based on the amount and duration of the flows of water. Drying events such as an extended drought could pull the system toward an **upland forest community or grassland**

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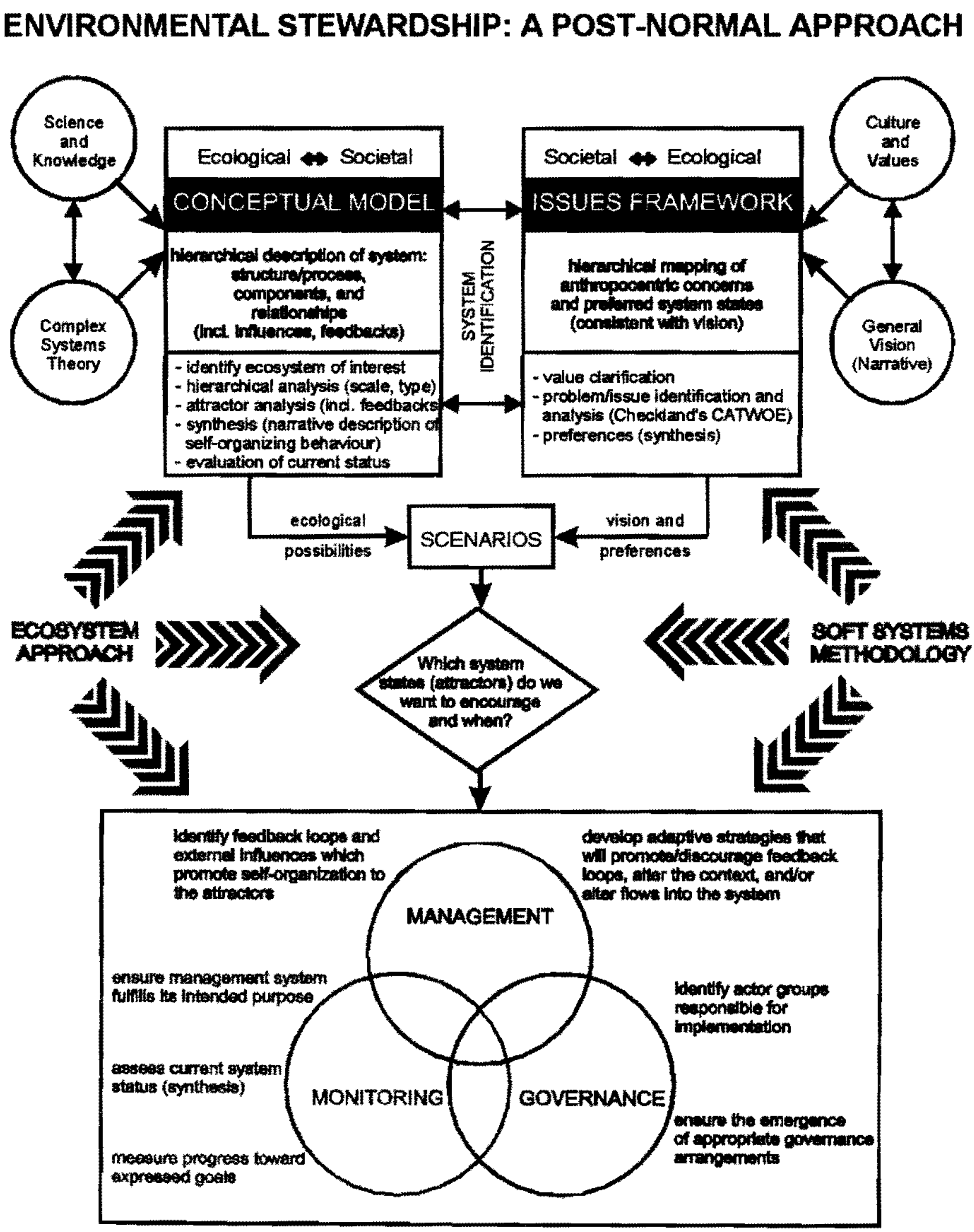
[16]Slocombe, 1993c is a collection of generic SOER sustainability criteria

[17]Funtowicz and Ravetz, 1993, 1994.

Figure 10


ENVIRONMENTAL STEWARDSHIP: A POST-NORMAL APPROACH
Science and Knowledge
Complex Systems Theory
Ecological ⇔ Societal
CONCEPTUAL MODEL
hierarchical description of system: structure/process, components, and relationships (incl. influences, feedbacks)
- identify ecosystem of interest
- hierarchical analysis (scale, type)
- attractor analysis (incl. feedbacks)
- synthesis (narrative description of self-organizing behaviour)
- evaluation of current status
SYSTEM IDENTIFICATION
Societal ⇔ Ecological
ISSUES FRAMEWORK
hierarchical mapping of anthropocentric concerns and preferred system states (consistent with vision)
- value clarification
- problem/issue identification and analysis (Checkland's CATWOE)
- preferences (synthesis)
Culture and Values
General Vision (Narrative)
ecological possibilities
SCENARIOS
vision and preferences
ECOSYSTEM APPROACH
SOFT SYSTEMS METHODOLOGY
Which system states (attractors) do we want to encourage and when?
identify feedback loops and external influences which promote self-organization to the attractors
develop adaptive strategies that will promote/discourage feedback loops, alter the context, and/or alter flows into the system
MANAGEMENT
ensure management system fulfills its intended purpose
identify actor groups responsible for implementation
assess current system status (synthesis)
MONITORING
GOVERNANCE
ensure the emergence of appropriate governance arrangements
measure progress toward expressed goals

(other attractors) with associated vegetation structure. If there are extended periods of flooding causing high water levels, the attractor would be that of a **marsh ecosystem**. This is because red and silver maple are tolerant to flooded conditions within 30% to 40% of the growing season. If flooding events are greater than this threshold, the forest trees will die, giving way to more water tolerant herbaceous marsh vegetation. (The feedback mechanism which maintains the swamp attractor is evapotranspiration (i.e. water pumping) by the trees. Too much water overwhelms the pumping capability of the trees and not enough shuts it down.)

A subdivision is about to built adjacent to the swamp. This could change the runoff into the swamp. (This is the human influence.) However we wish to maintain the swamp. So the question becomes how much can the runoff change before the swamp flips into the domain of one of the other attractors? It turns out that we don't know the current runoffs, or what changes can be allowed and would take several years of data collection to determine this. So the only way to be sure to maintain the integrity of the swamp is for the developer to build in a way which does not alter the drainage patterns into the swamp.

In appendix 2 there is a discussion of how to apply these ideas to a real site. It is incomplete as we are still learning how to execute the methodology. However we have learnt several lessons worth highlighting. The *nested holon approach* allowed us to systematically (using the ABCE method) identify the *influences* which were likely to affect the ecosystem's integrity. This guided our choice of what information to collect and the geographical extent which must be covered. It also allowed us to identify the *self-organizing characteristics* of the ecosystem that needed to be investigated. In essence this provided us with the *framework* for monitoring for this site. Having said this, it did, however, take us much work to establish the nested holons and information required for each holon, and we are only starting to collect the necessary data This approach also explicitly connects the ecosystem to the outside world, thus it is being analysed in context. The discussion of attractors makes it explicit for decision makers, that they must decide what they want on the site, and that this decision must be made in the context of adjacent human use of the land. (For example, the swamp or marsh or forest of the previous example.) Having said this, it must be noted that there is a dearth of information about what the potential attractors are and what the thresholds for flips are, as the science of ecology has only just begun to ask these questions. The study of ecosystem as complex systems is just beginning.

In closing then, we must always remember that left to their own devices, living systems are self-organizing, that is they will look after themselves. (A damaged ecosystem, left to its own devices, has the capability to regenerate, if it has access to the information required for renewal, that is biodiversity, and if the context for the information to be used, that is the bio-physical environment, has not been so altered as to make the information meaningless.) The challenge facing the practice of environmental management is to learn how to work with these self-organizing processes in a way which allows us to meet our species needs, while still preserving the integrity of ecosystems, that is to say the integrity of the self-organizing processes. Put in a more positive way, the challenge is to manage human activities so as to enhance the natural developmental processes ongoing in ecosystems while doing those things we wish to do. It is not ecosystems that need management, it is our use of the landscape. But we can have our cake and eat it too. By managing our activities to enhance ecosystem self-organization, we will enhance the free benefits we receive from the biosphere. It is a question of understanding the self-organizing processes in ecosystems and then managing our actions so they interact synergisticly with these self-organization processes. Only by acknowledging that the essence of ecosystems is self-organization, and our responsibility for maintaining these self-organizing process, will we assure our species a sustainable niche in the biosphere. *And this therefore is the focus of Monitoring, evaluating the integrity of ecosystems as self-organizing entities, and the state of our influence, both positive and negative, on this integrity.*

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Appendix 1

The *Ecosystem Approach* to evaluating *ecological integrity*

A. Define the ecosystem

Hierarchy (The vertical perspective, what is a part of what?)
    Define the Nested Holons (nested living systems); this defines the contextual relationships.
Scale and Extent (the horizontal perspective, where do things begin and end?)
    What are the boundaries of observation?
    What are the processes which define the whole?
    What are the boundaries of the ecosystem, the holon of focus?
Structure
    The vertical and horizontal connections between holons

B. Describe the ecosystem as a self-organizing entity

Non-Linear Models: The synergistic relationships, the cycles, the feedback loops, virtual worlds.

The attractors (organizational states) and their domains:
    What are the attractors?
        In what direction will the ecosystem tend to develop? What are its propensities?
            (Self-organization theory of dissipative structures helps answer this.)
    What is the behaviour of the ecosystem about the attractors?
        (Homeostatic, Stable, Figure ∞, Unstable but persists, chaotic?)
    Are there bifurcation points?
    What are the potential flips between attractors?
        What triggers the flips?
        How can we monitor for them?

What is the interplay of energy, exergy, information and environmental conditions (in space and time) which shapes the ecosystem?
    Think carefully about the Figure ∞, their scale and extent, the nested holons and their interactions and connections, the information available to the ecosystem, and the environmental conditions it must live with.
    (Ecological history and non-equilibrium thermodynamics help answer this)

C. How do we evaluate *Integrity* for this ecosystem?

(What states of ecosystem organization are acceptable to us?)

What are the ecological processes (at each of the nested levels) we value and/or need?
    How do we identify these?
    How do we measure the status of these processes?
    (Notice that this takes us back to step A above)
Which attractors represent unacceptable ecosystem conditions?

D. Is this *integrity* threatened?

What are the external forces which could effect the organizational status of the system?
Use the nested ABCE methodology to identify the external influences on the organization of the ecosystem. (stress-response ecology)
What are the thresholds of flips to the unacceptable attractors? (states of ecosystem organization)
How do we monitor to make sure these thresholds are not crossed?

E. How do we maintain *integrity* in this system?

How do we mitigate known threats?
How do we promote positive influences? (For example; fire in a prairie)
How do we monitor the ecosystem so as to detect changes due to previously unidentified external influences?

F. How to deal with Emergent Complexity.........

When all is said and done, our ability to predict is severely limited. Unexpected events and trends will occur. Surprise will happen, complexity will emerge. We must therefore rely on anticipatory and adaptive management.

Always remember "The system imbedded in another system imbedded in another system imbedded in another system ...." and the challenge of sustaining a dynamic, changing, evolving, self-organizing ecosystem.

Appendix 2

The Ecosystem Approach Applied to Huron Natural Area.[1]

The city of Kitchener and the Waterloo County school board are in the process of purchasing a property which contains a mixture of wetlands, trout streams, ponds, fields, and lowland and upland forest both natural and plantations. It is a rich mix of the ecosystem types found in south western Ontario. The property is bounded by suburbia, industrial and agricultural land.

Our task is to advise on the ecological integrity of the site. Our approach to this task is still under construction so this report is only partial. Also we have several hundred pages of consultants reports and student papers, all of which can't be presented here, but much of which is relevant. We have not yet got to the stage of understanding which allows us to distill things down to a few dozen pages. What follows are the pieces we have in brief.

Throughout we used the ABCE methodology which is an adaptation of Dorney's ABC methodology. This methodology allows us to use different disciplinary perspectives without loosing our sense of the whole.

Organizing Principle	System Perspectives
ABIOTIC	Air Sheds Water Sheds Geomorphology
BIOTIC	Wildlife (Species) Communities Landscape
CULTURAL	Human Use of Land Cultural and Historical Significance
ENERGETICS	Energy Flows Nutrient Flows

The ecosystem approach is both analytic and synthetic. It involves analysis of living systems by disciplinary science. But understanding comes from synthesizing together the different perspectives gained from disciplinary science. These two phases of the ecosystem approach, as they apply to this undertaking, are portrayed in the following diagram. In the first phase all the communities are examined by each discipline. In the second each community is examined by all the disciplines in order to get a integrated understanding of the whole

Applying the Steps in the Ecosystem Approach

A. Define the ecosystem

Hierarchy (The vertical perspective, what is a part of what?)
- Define the Nested Holons (nested living systems); this defines the contextual relationships.

Scale and Extent (the horizontal perspective, where do things begin and end?)
- What are the boundaries of observation?
- What are the processes which define the whole?
- What are the boundaries of the ecosystem, the holon of focus?

Structure
- The vertical and horizontal connections between holons

[1]Ryan Metcalfe, Steve Diggon, Carl Burgess, Robin Greene, Marnie Eggen, Brian McHattie, Mark Conrad, Clint Johnson are undergraduate ERS students who have worked on developing a framework for monitoring ecosystem integrity in the Huron Natural Area. This work has been supervised by Prof. James Kay in consultation with Kitchener Parks and Recreation dept. staff

Our *ecosystem* boundaries are set by the property lines on the site which is determined by the City of Kitchener in conjunction with the school board. Our temporal focus is long term.

We choose four levels to focus on inside the ecosystem:

the landscape,
the communities,
the populations,
the individuals.

The park is part of:

a *wider system*, the Strasburg Creek sub watershed,
whose *environment* is the Grand River watershed
which is part of the *wider environment* of the Great Lakes Basin, particularly southwestern Ontario.

These relationships are best described by the figures and maps on the next pages.

Site Type	# of hectares	% of area
Natural Forests		
upland hardwoods	21.2	14.4
soft maple swamp	6.5	4.4
conifer swamp	1.4	1.0
coniferous and mixed woods	13.8	9.4
other wetlands	49.5	33.6
sub-total	92.4	62.6
Modified Communities		
conifer plantation	3.0	2.0
old fields and second growth	26.1	17.7
active agriculture	3.7	2.5
anthropogenic (gravel pits etc.)	13.7	9.2
open water	8.3	5.8
sub-total	55.1	37.4
Total	147.5*	100.0

B. Describe the ecosystem as a self-organizing entity

Non-Linear Models: The synergistic relationships, the cycles, the feedback loops, virtual worlds.

The attractors (organizational states) and their domains:
- What are the attractors?
  - In what direction will the ecosystem tend to develop? What are its propensities?
    - (Self-organization theory of dissipative structures helps answer this.)
- What is the behaviour of the ecosystem about the attractors?
  - (Homeostatic, Stable, Figure 8, Unstable but persists, chaotic?)
- Are there bifurcation points?
- What are the potential flips between attractors?
  - What triggers the flips?
  - How can we monitor for them?

What is the interplay of energy, exergy, information and environmental conditions (in space and time) which shapes the ecosystem?
- Think carefully about the Figure 8, their scale and extent, the nested holons and their interactions and connections, the information available to the ecosystem, and the environmental conditions it must live with.
- (Ecological history and non-equilibrium thermodynamics help answer this)

We are currently doing this on a community by community basis. It has been done for wetlands, streams and upland woods. Ecological analysis usually focuses on inventorying species and sometimes habitats. Our analysis focuses on processes, particularly the figure 8. What emerges is a rich description of the changes in the communities as they go through their annual and other cycles. Particular emphasis is placed on identifying events which occur infrequently but have substantial impact on the community (windstorms, floods, harvest for example). In this regard we have found the knowledge of local people to be invaluable. One family has kept records with maps and photos of how the site has changed since the turn of the century. We also have a series of air photos which go back to the 1930s. The most difficult challenge facing us is the identification of the different attractors.

Some examples of different attractors and potential flips:

For example, the closed soft maple swamp in the wetland community could be pulled toward different attractors based on the amount and duration of the flows of water.

a) Drying events such as an extended drought could pull the system toward an upland forest community or grassland with associated vegetation structure.

b) If there are extended periods of flooding causing high water levels, the attractor would be that of a marsh ecosystem. This is because the red and silver maple are tolerant to flooded conditions within 30% to 40% of the growing season. If flooding events are greater than this threshold, the forest trees will die, giving way to more water tolerant herbaceous marsh vegetation.

C. How do we evaluate *Integrity* for this ecosystem?

(What states of ecosystem organization are acceptable to us?)

What are the ecological processes (at each of the nested levels) we value and/or need?
How do we identify these?
How do we measure the status of these processes?
(Notice that this takes us back to step A above)
Which attractors represent unacceptable ecosystem conditions?

What follows are the **activities** and **characteristics** which determine/describe the **organization** and thus the integrity of each of the nested levels within the ecosystem. It is not sufficient to simply describe these as they now are, but to also explore how they will be affected by environmental change and how they will evolve over time, paying particular attention to figure 8 and catastrophic behaviour. All of this is in the context that we do not wish this site to be altered by external human influences, but it is to be used for recreation and education.

We have only established in the broadest of terms which attractors are unacceptable. For example; clear cutting the forest plantations on site, or leaving these same age stands to collapse all at once, or the invasion of the wetlands by purple loosestrife spreads.

The Landscape

Organizing Principle	System Perspectives	Characteristics/Activities
Abiotic	Air flows	Patterns of air flow Micro climate issues
	Water flows	Surficial (energy/nutrients) Ground (energy/nutrients)
	Geomorphology	soils/landforms
Biotic	Wildlife	Movement patterns Breeding grounds or wintering grounds Existing exotics

	Communities	Inter spatial and temporal relationship (annual and longer term)
Cultural	Human Use	Compaction of soils Littering Transportation routes and paths People walking pets/wandering pets
	Cultural Value	Education Recreation Hunting/fishing Resource extraction Speculation/profit
	Historical	land use patterns habitation resource extraction hunting Archaeological sites
Energetics	Energy	Productivity, respiration, biomass
	Nutrients	Nutrient flows

The Communities

Organizing Principles	**System Perspectives**	**Characteristics/Activities**
Energetics	Energy and Nutrients	overall energy balance the food web trophic structure nutrient cycles
Biotic	Wildlife	major populations and their niche interactions ( ) -competition -symbiosis spatial and temporal distribution ( ) existing exotics
Abiotic	Air flows	patterns of air flow micro climate issues
	Water flows	surficial (energy/nutrients) ground (energy/nutrients)
	Geomorphology	soils erosion
Cultural	Human Use	student study of community transportation routes and paths compaction of soils people walking pets/wandering pets littering vandalism harvesting of wildlife

Populations

Population Dynamics
population density minimum viable population size interspecific competition intraspecific competition demographics of population predator prey relations growth and reproductive rates realized niche

D. Is this *integrity* threatened?

What are the external forces which could effect the organizational status of the system?
Use the nested ABCE methodology to identify the external influences on the organization of the ecosystem. (stress-response ecology)
What are the thresholds of flips to the unacceptable attractors? (states of ecosystem organization)
How do we monitor to make sure these thresholds are not crossed?

So for each hierarchical level, **outside** the ecosystem, we have done an ABCE analysis of factors which effect self-organization **within** the ecosystem and thus need to be monitored and studied:

The Wider Environment
GREAT LAKES BASIN (CENTRAL SOUTH WESTERN ONTARIO)

The Great Lakes Basin, in particular Central South Western Ontario, has been identified as the largest geographical extent which will influence the Huron Natural Area. This geographic boundary is specifically chosen to account for all flows that run into the study area. This outer most hierarchical level will form the 'wider environment' which will be studied and monitored. The effects of both point and non point sources of air pollution coming from outside the 'Wider Environment' also need to be considered and monitored.

Organizing Principle	System Perspective	Influences
Abiotic	Airshed	pollution sources -point sources (industrial) -non point sources (agricultural, automobiles, etc.) weather patterns
Biotic	Wildlife	migratory species (fowl) exotic species (e.g. zebra mussels, purple loose strife)
	Landscape	All interactions provided by the structure or isolation of corridors and patches

The Environment
GRAND RIVER WATERSHED

Organizing Principle	System Perspective	Influences
Abiotic	Airshed	pollution sources -point sources (industrial) -non point sources (agricultural, automobiles, etc.) weather patterns -heat island effect from Tri-City area
	Watershed	ground water -recharge areas -aquifers

		surficial -flooding -runoff
Biotic	Wildlife	local movement- species move in and out of the Strasburg Creek Watershed from the Grand River Watershed (i.e. deer, coyote's, etc.) migratory species (fowl) inundation of exotic species
	Landscape	All interactions provided by the structure or isolation of corridors and patches
Cultural	Human Use	rural, suburban, urban, industrial interactions

The Wider System
STRASBURG CREEK SUB WATERSHED

Strasburg Creek sub-watershed (The Wider System), is located within the Grand River Watershed. Everything which impacts this sub-watershed has an effect on the study area. All water from this level drains directly into and through Huron Natural Area. For this specific reason, all four components of the organizing principle are needed at this extent to identify the influences on the integrity of the Huron Natural Area.

Organizing Principle	System Perspective	Influences
Abiotic	Airshed	pollution sources - point sources (industrial) - non point sources (agricultural, automobiles, etc.) weather patterns - (micro climate)
	Watershed	surficial -Strasburg Creek itself -run off ground water -hydraulic head -recharge areas -aquifers precipitation -quantity -quality (chemical composition) pollution - point and non point sources
Biotic	Wildlife	local - species move in and out of the Strasburg Creek Watershed migratory species inundation of exotic species (Purple Loose strife) local pets can be very destructive (especially cats to bird populations)
	Communities	Identification of surrounding communities and their interaction with the park ( )
	Landscape	All interactions provided by the structure or isolation of corridors and patches
Cultural	Human Use	Rural, Suburban, Urban, Industrial interactions with the park
Energetics	Energy	detrital matter flow via water detrital matter flow via wildlife
	Nutrients	water via organisms airborne organics

Again this is a list of influences, but it does not deal with the dynamics of the effects of the influences on the organization and hence integrity of the Huron Natural Area. But it does identify the aspects which need to be studied.

E. How do we maintain *integrity* in this system?

How do we mitigate known threats?
How do we promote positive influences? (For example; fire in a prairie)
How do we monitor the ecosystem so as to detect changes due to previously unidentified external influences?

This is the question we have dealt with the least. A few threats which need to be dealt with quickly have been identified:

An asphalt plant on site is being shut down.

Drainage patterns from new sub divisions must be understood as there is reason to suspect that they will fundamentally change the nature of the wetlands on site. The wetlands could be subjected to an increased duration of water flow and also runoff from lawns and roads which will limit some vegetation and may reduce breeding habitats, food sources and promote the spread of exotic species. Rather than take remedial action, altering the subdivision plan before construction to avoid these problems is being pursued.

Invasion by Purple Loosestrife, which spreads quickly and chokes out natural vegetation, limiting habitats and species diversity, would force the wetland to a dry land ecosystem (a new attractor for the wetlands which represents an unacceptable condition).

The loading of phosphorus (runoff from fertilizers, cleared land) induces an explosion of algal growth which can choke the stream ecosystem by causing eutrophic conditions which upset habitats and food sources for resident species and give way to other fish species.

F. How to deal with Emergent Complexity.........

When all is said and done, our ability to predict is severely limited. Unexpected events and trends will occur. Surprise will happen, complexity will emerge. We must therefore rely on anticipatory and adaptive management.

This project started out explicitly using an ecosystem approach and this is the approach used by the City of Kitchener in its planning and parks and recreation departments. So a bureaucracy is in place that has this focus already. A steering committee has been established which will focus on maintaining the integrity of the area while allowing its use for recreation and education. The mandate of this committee is stewardship of nature and management of human use of the ecosystem. This is seen as an ongoing adaptive process.

Panel Discussion

Mario Giampietro, INN, Rome

Figures 1 through 6 and the following list of indicators comprise the overheads used by Mario Giampietro in his presentation.

Indicators for System Health

There are a number of different sets of indicators. The sets identified here include: ecological context, socio-economic context, material standard of living at the household level, and the degree of freedom from local biophysical constraints.

1. Ecological Context

Indicators of stress must cover different scales:

Global level
Regional level
Watershed level
Village level
Farm level
Field level
Soil level

They can refer to:

(i) Direct measurement of environmental loading eg. Kg of pesticide or fertilizers per hectar per year; pollutants discharged into the environment
(ii) Assessment of alteration of matter and/or energy flows eg. W/kg; W/square metres; other thermodynamic indicators; densities of nutrient flows
(iii) Bioindicators eg. Key species giving information on the health of the natural system within which they operate; vegetal associations; biodiversity assessment
(iv) Landscape pattern eg. Fractal dimension of agricultural landscape; hierarchical organization in space and time of matter and energy flows.

2. Socio-Economic Context

• Average body mass	30-60 kg
• THT/C	10-45
• Dependency on importation for food security	0-50%
• Exo/endosomatic energy ratio	5-90
• BEP	15-1600 Mj/hour
• Exosomatic metabolic flow	35-900 Mj/cap/day
• Cereal surplus per hectare	-3000 +4000 kg/ha arable land
• Cereal surplus per hour	-1 +85 kg/hr agricultural labour
• Cost of agricultural surplus	-13 +37 US$/hour labour
• GNP/capita	90-36000 US$/cap/yr
• ARL	.10-45 US$/hour
• Expenditure for food	6-60% og GDP

• Total food energy supply	1500-4000 kcal/cap/day
• Total protein supply	30-130 g/cap/day
• Animal/total protein ratio	15-70%
• % labour force in agriculture	4-70%
• Farmer income vs national income average	0.6-1.0
• GDP in agric vs labour force in agriculture	.10-1.5
• Agricultural taxes/subsidies ratio	
• Prevalence of child malnutrition	.5-6-%
• Infant mortality	4-170/thousand
• Child mortality	6-320/thousand
• Low birth weight	4-40%
• Life expectancy	39-79 years
• Population/physician ratio	210-73,000
• Population/hospital bed ratio	65-65,000
• Pupil/teacher ratio	6-90
• Illiteracy ratio	.5-90%
• Radio ownership	25-2,100/thousand
• Television ownership	1-820/thousand
• Car ownership	.5-570/thousand

3. Material Living at the Household Level

• Average body mass	34-60kg
• THT/C	10-45
• Dependency on market for food security	0-100%
• Endosomatic metabolic flow	6.5-9.5 Mj/cap/day
• Exosomatic metabolic flow	35-900 Mj/cap/day
• NDC	50-50,000 US$/cap/year
• ARL	.10-45 US$/hour
• Expenditure for food	5-75% of NDC
• Total food energy supply	1500-4000 kcal/cap/day
• Total protein supply	30-130g/cap/day
• Animal/total protein ratio	15-70%

4. Degree of Freedom from Local Biophysical Constraints

• Dependence on fossil energy	0-90%
• Dependence on imported inputs	0-100%
• Dependence on imported foods	0-50%
• Ecological foot print	
• Natural flow boosting ratio	1-50
• Ha/year equivalent on ha/year actual ratio	

Figure 1

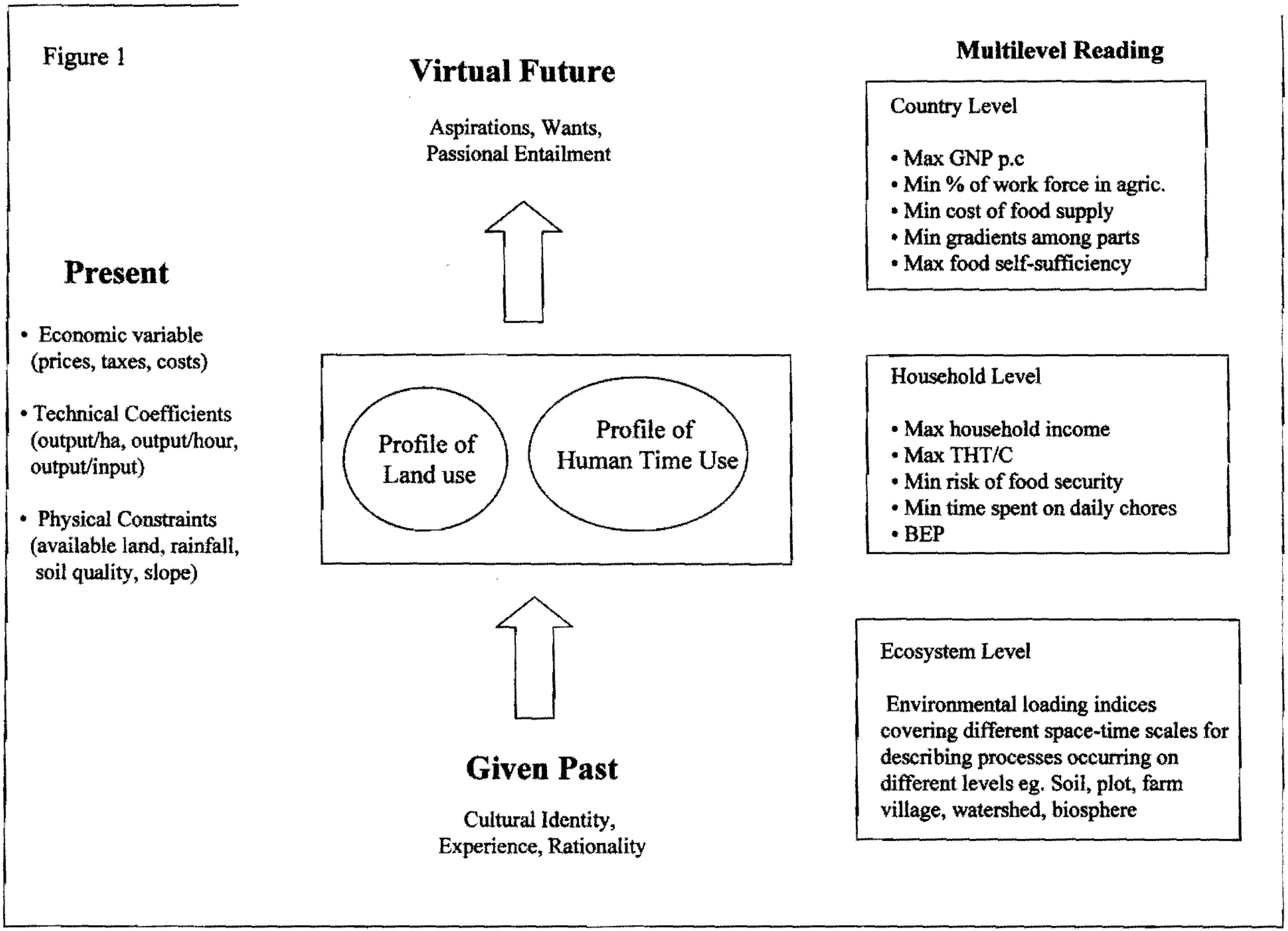
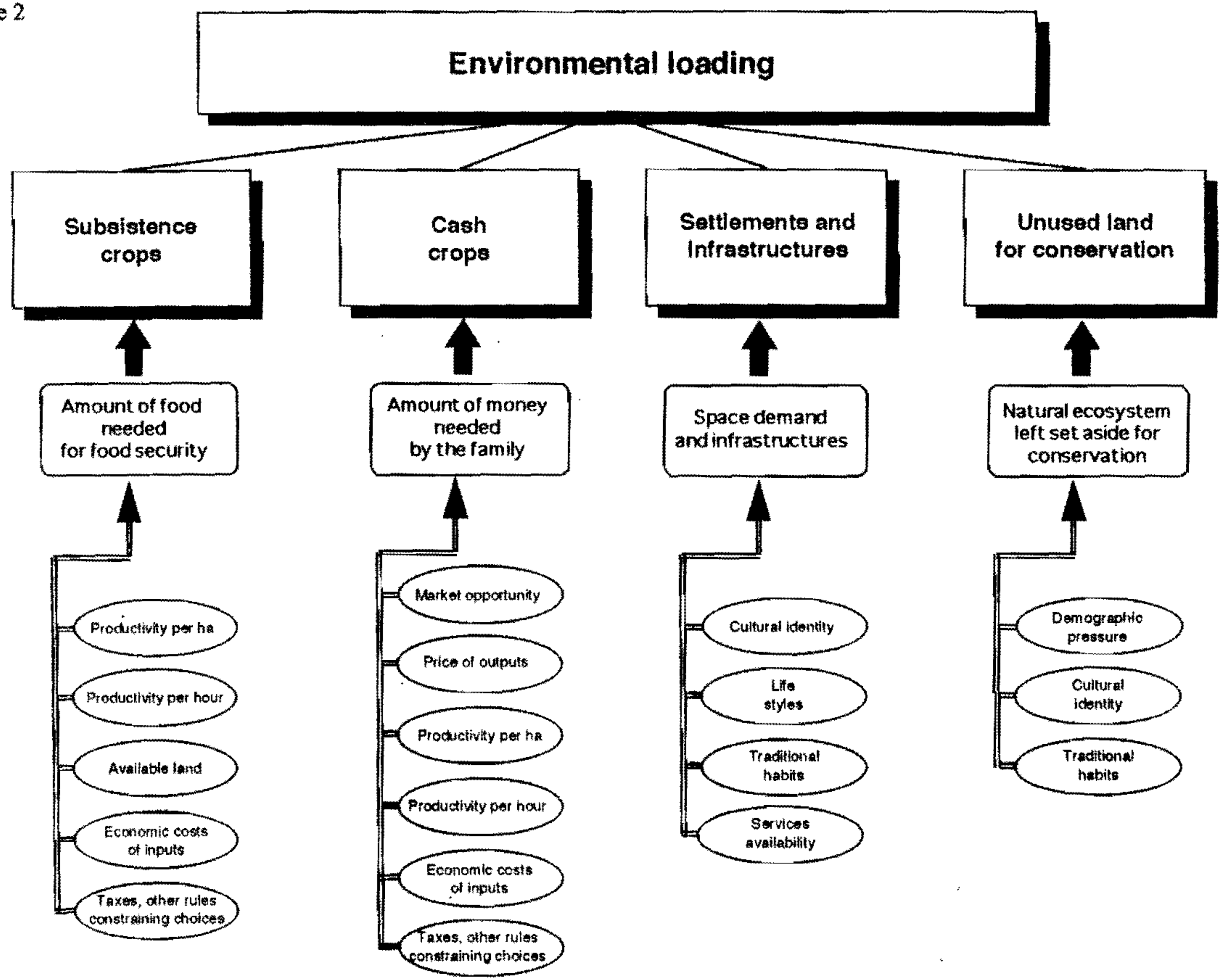

Virtual Future
Aspirations, Wants,
Passional Entailment
Multilevel Reading
Country Level
• Max GNP p.c
• Min % of work force in agric.
• Min cost of food supply
• Min gradients among parts
• Max food self-sufficiency
Present
• Economic variable (prices, taxes, costs)
• Technical Coefficients (output/ha, output/hour, output/input)
• Physical Constraints (available land, rainfall, soil quality, slope)
Profile of Land use
Profile of Human Time Use
Household Level
• Max household income
• Max THT/C
• Min risk of food security
• Min time spent on daily chores
• BEP
Ecosystem Level
Environmental loading indices covering different space-time scales for describing processes occurring on different levels eg. Soil, plot, farm village, watershed, biosphere
Given Past
Cultural Identity,
Experience, Rationality

Figure 2



Environmental loading
Subsistence crops
Cash crops
Settlements and infrastructures
Unused land for conservation
Amount of food needed for food security
Amount of money needed by the family
Space demand and infrastructures
Natural ecosystem left set aside for conservation
Productivity per ha
Productivity per hour
Available land
Economic costs of inputs
Taxes, other rules constraining choices
Market opportunity
Price of outputs
Productivity per ha
Productivity per hour
Economic costs of inputs
Taxes, other rules constraining choices
Cultural identity
Life styles
Traditional habits
Services availability
Demographic pressure
Cultural identity
Traditional habits

Figure 3

The Amoeba approach

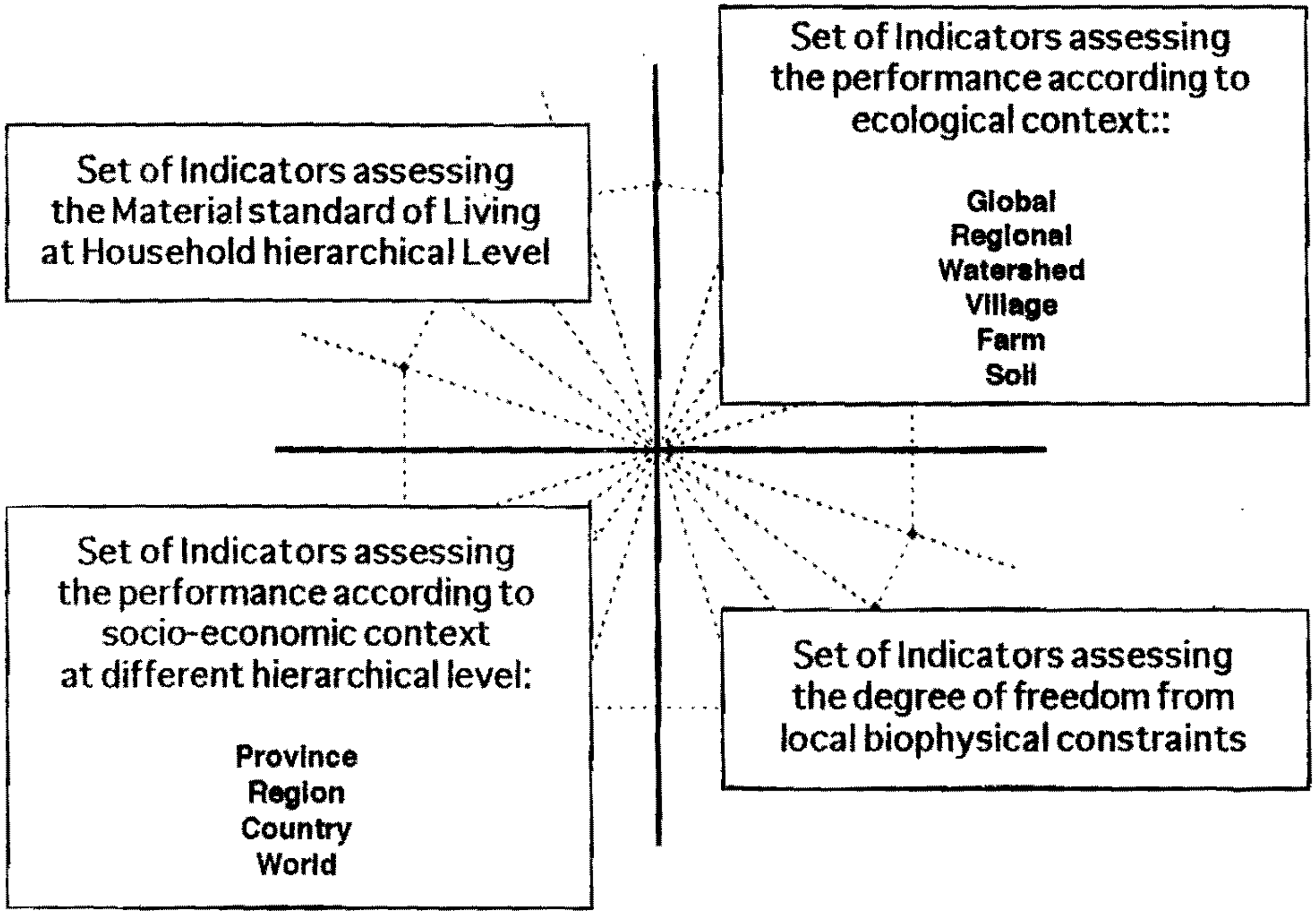


Figure 4

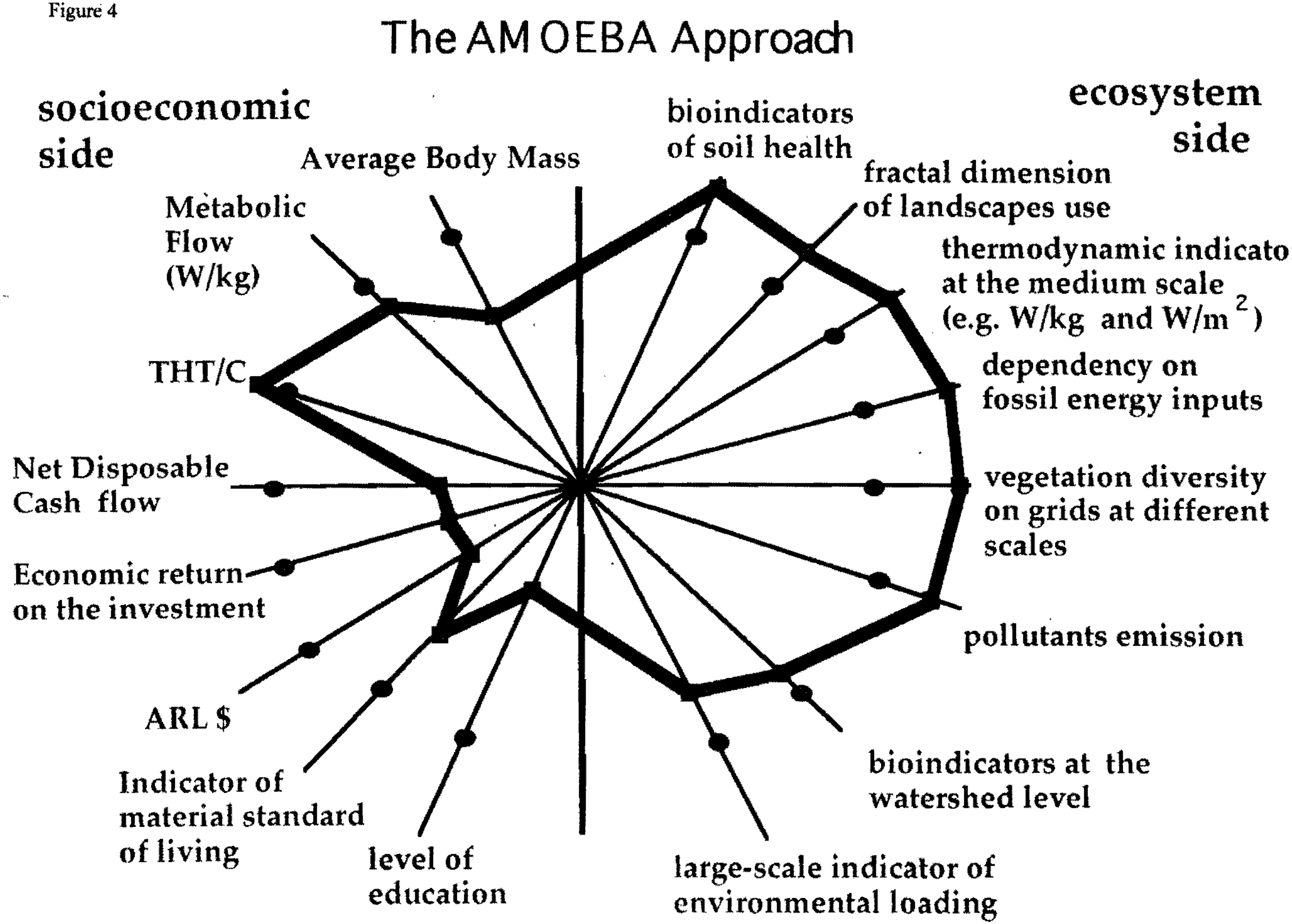
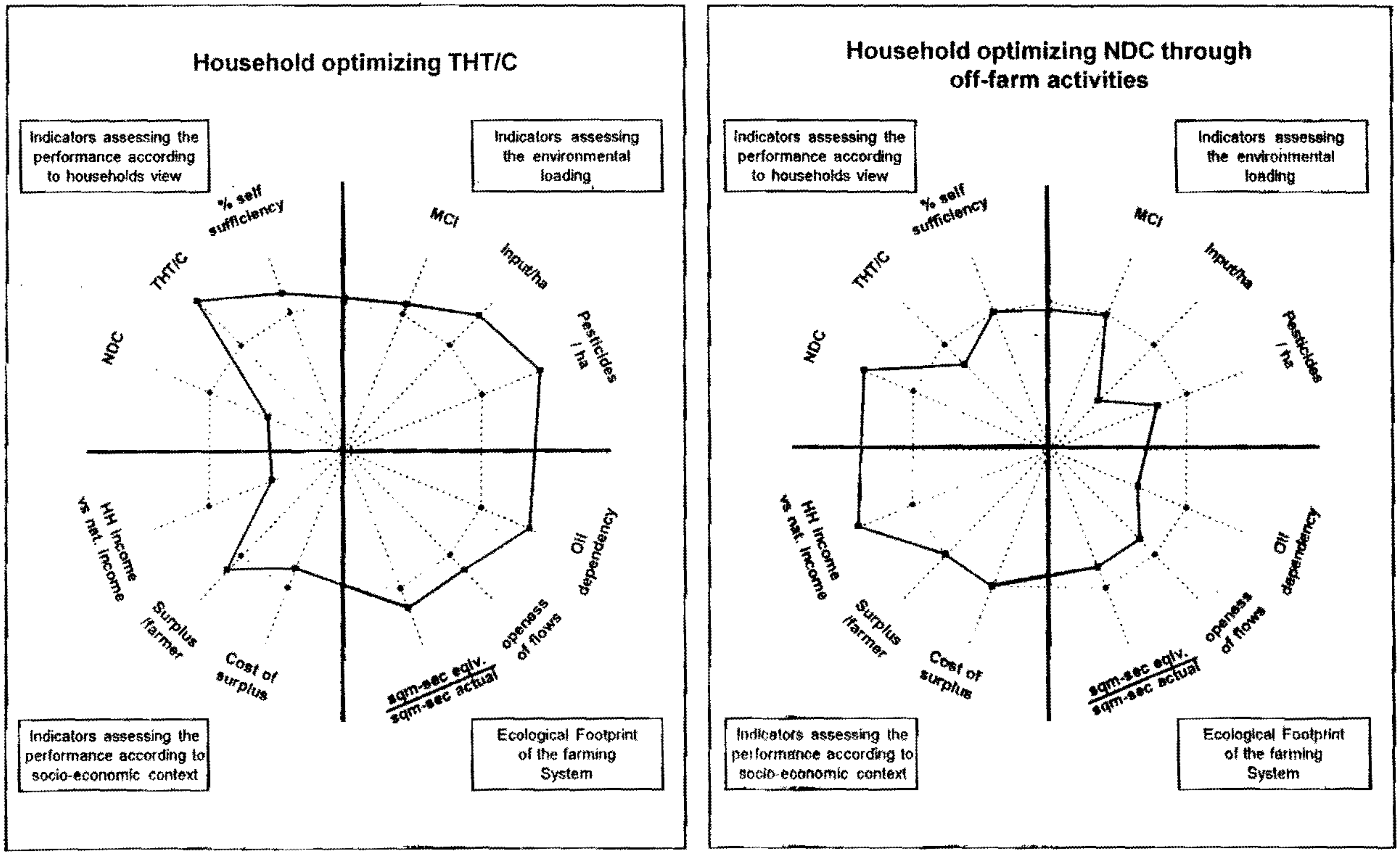
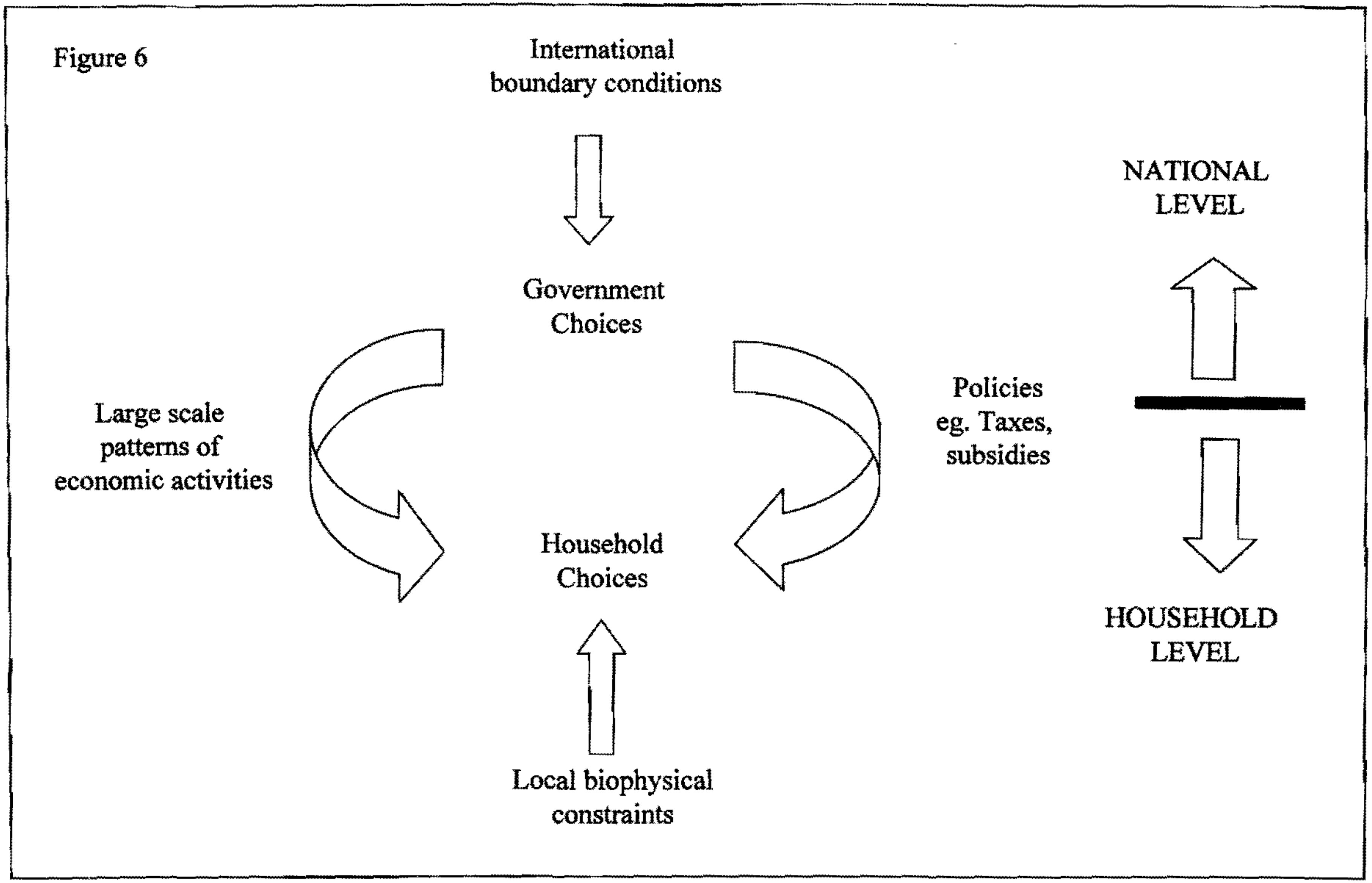

The AMOEBA Approach
socioeconomic side
ecosystem side
Average Body Mass
Metabolic Flow (W/kg)
THT/C
Net Disposable Cash flow
Economic return on the investment
ARL $
Indicator of material standard of living
level of education
large-scale indicator of environmental loading
bioindicators at the watershed level
pollutants emission
vegetation diversity on grids at different scales
dependency on fossil energy inputs
thermodynamic indicator at the medium scale (e.g. W/kg and W/m 2)
fractal dimension of landscapes use
bioindicators of soil health

Figure 5

Examples of application of Amoeba Approach





This figure presents the idea that vertical interaction of each level can be described in terms of changes in profile distribution of the lower level holons over the space of accessible states.

Review of Some Critical Concepts

Gilberto C. Gallopín

The purpose of this brief presentation is to highlight some critical concepts derived from complex systems and dynamical systems theories that may be useful in the study of real agroecosystems; I will try to look to the basic meaning, rather than to the formal aspects.

The first relevant concept is that of **state**. In the most general terms, a state is "any well defined condition that can be recognized if it occurs again" (Ashby)

The **state of a system** is specified by a list of the values (not necessarily numerical) taken at a given moment by each of the variables representing the system. Each is a state variable. Each can be visualized as specifying an axis of a coordinate system. Thus, the state of the system is represented by a point in the coordinate system.

The **state (phase) space** is a subset of n-dimensional space, defined as the totality of possible points for the system (e.g., non-negative population densities)

- The state space is the space *of the possible*: it contains not just what happens but what might happen under different circumstances.
- Attractors (and repellers) are *subsets of the state space* (points, limit cycles or orbits, torii, higher-dimensional attractors, strange attractors)

Therefore, which attractors exist or can be identified depends on how the state space is defined (e.g. for the whole system, or for a subsystem)

In due course, a system led to itself will end up into one or another of its (finite) number of attractors. The attractors can be visualized (metaphorically) as depressions in a "stability landscape" to which the state of the system (viewed as a ball or marble) tends to fall. Thus, the different attractors constitute *the total number of alternative long-term behaviors of the system.*

Since the system follows trajectories that inevitably flow into attractors, tiny attractors will "trap" the system into tiny subregions of its state space.

- The attractors, if small relative to the total state space, "create" order (even in the case of strange attractors). Thus, the existence of attractors "reduces" the problem.

Another important concept is that of **dynamical system**, a concept rich in potentially useful concepts even if it is not formally applied to a complex case-study. In general terms, a formal dynamical system includes:

- State ("phase") space

  \+

- Rules of change (equations of motion, or dynamical equations, or evolution equations, or vector field):

$$\begin{cases} \dfrac{dX_1}{dt} = F_1(\{X_1,\ldots X_n\},\ \lambda) \\ \vdots \\ \dfrac{dX_n}{dt} = F_n(\{X_1,\ldots X_n\},\ \lambda) \end{cases}$$

where λ = control parameter (depending on the external world; may represent a gradient with the environment)

The forces of motion (and gradients) are imbedded in the equations, *they are not the attractors.* Attractors are particular solutions of the equations of motion (e.g. for $dX_i/dt=0$)

One conclusion in terms of the application of those notions to the case of Ucayali/Pucallpa is that the *goals* of the social actors are part of the forces of motion, they are not the attractors.

In a very naive form, if the interest lies in the relationships between "development" (as measured by economic growth, quality of life, or any other relevant indicator) and renewable natural resources, the system could be described as follows:

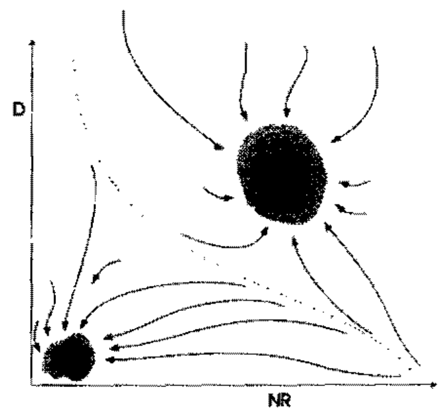
Let *NR* = natural resources, and *D* = development level

state = (development level, natural resources)

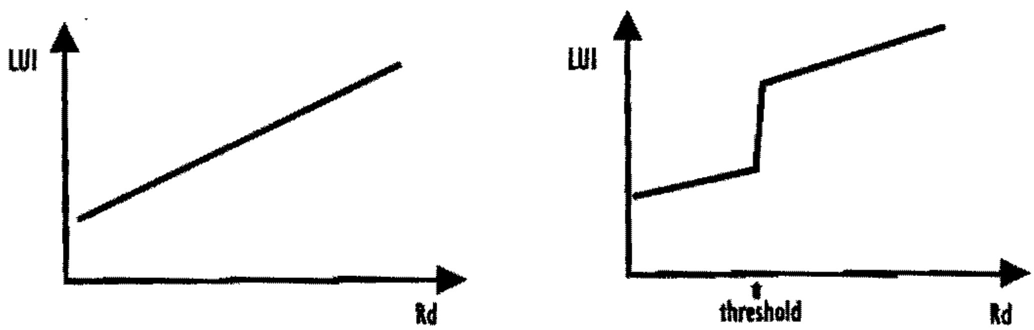
and

$$\begin{cases} \dfrac{dX_1}{dt} = d(development)/dt = F(NR,\ D,\ social\ goals) \\ \dfrac{dX_2}{dt} = d(natural\ resources)/dt = G(NR,\ D,\ environmental goals) \end{cases}$$

The attractors are sets of values of (Development, Natural Resources)



Another issue that needs more thinking is that of **roads** as attractors in the case of Ucayali. This is rather complicated. If roads are viewed as attractors, the spacial distribution must be included in the phase space. On the other hand, *road density* (Rd) might be a parameter for *land use intensity* (LUI):



Changing stability landscapes

The stability landscape itself may change.

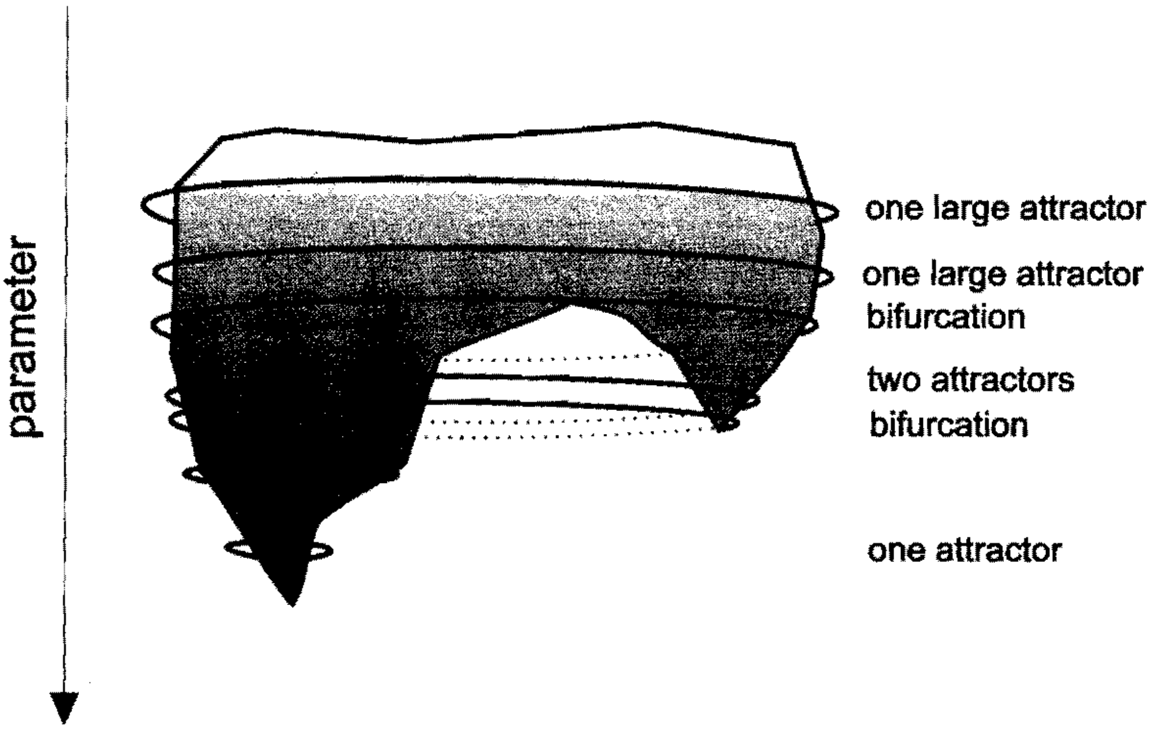
Any system has variables that are held practically constant and are called *parameters* of the dynamical system.

If a system has a number of parameters, one can imagine, similarly to the state space, a *parameter space*, where each axis corresponds to one parameter. A point in parameter space refects a specific combination of all parameter values.

Any point in parameter space corresponds to a fixed set of basins of attraction and attractors in the corresponding state space of the dynamical system.

Each point in parameter space specifies the dynamical system defined in the differential equations and hence also specifies its state space and all its basins of attraction.

As the parameters change slowly, some or all of the trajectories and basins of attraction also change slowly. However, for particular values of the parameters, dramatic changes (*bifurcations*) may occur. A basin may contract to nothing, or a new basin may appear.



Implications for use of those concepts to messy complex systems

• Issue: how to define the state space for Pucallpa (non trivial)

• Issue: how to decide whether the system has attractors and which are they if we do not have a good mathematical model of the system (the usual situation). This is a difficult problem. Use history? Look at projections in lower dimensionality spaces? Look at the forces acting, gradients, etc.? How to deal with a new system being created (which is the case of a system in development)?

• Attractors, phase space and other concepts discussed above should be used as metaphors, generating new questions and viewpoints and helping to focus attention on posible system behavior and underlying dynamics, rather than as rigorous hypothesis and explanations.

The Research Process

***Tamsyn Murray*, CIAT**

The primary goal of this project is to develop a framework that can guide agricultural research. Therefore we not only wish to provide new concepts and forms of analysis to better understand agroecosystems, but also develop a research process, a method, that will outline for future researchers the necessary steps to be taken to achieve a more complete understanding of the system. Figure 1 represents the second draft of such a proposed research method, the main revision on the previous version being the change in the order sequence. It was agreed that the scaling process, ie. Definition of the systems and its boundaries, should come after the history of the system has been described and after the critical problems and issues have been identified. It would seem that the system of interest would be determined by the problems at hand.

We have identified a series a steps through which both researchers and stakeholders progress. Although there is a particular sequence to the process, the whole process is iterative. As new information is discovered past stages are revisited and modified. The differing roles and responsibilities of the scientists and stakeholders must be explicit.

The following section includes brief descriptions of the different steps identified:

Historical Reconstruction

In order to discover the dynamics of the system, repeating patterns, critical processes and cause-effect relationships, the history of the system needs to be reconstructed. In this project we separated key developments into ecological, economic, demographic, political and cultural dimensions. In addition we focused on changes in the pattern of organization i.e., the configuration of relationships among the system's components that determines the system's essential characteristics, changes in structure and process.

Problem(s) Analysis

During this step the critical management goals and objectives are identified. This helps to highlight the key issues or problems that are of interest to the stakeholders. Once the objectives are defined, the indicators that allow one to assess the performance of such objectives are identified.

Scaling

There are two parts to this process. First the system of interest is defined and delimited, as not all aspects of the system can be included. The boundaries both in time and space are identified, ie. what is the extent of the system and over what time period are we concerned. In addition we need to identify what type of system it is, eg. agricultural, fisheries, or forestry system. This defines our perspective, clarifies what is of interest to the observer (trees, food, income). Second, the system is situated within a nested hierarchy and the key contextual relationships with higher and lower systems in this hierarchy are identified. In scaling we are able to begin to highlight the cross-scale interactions and the level at which important emergent properties become evident.

Subsystem Models

Problem(s) analysis leads naturally on to the description of various subsystems models that detail the different system variables on interest. Focussing on subsystems allows simplification of different processes across time and space, and allows one to clarify the key interactions and influences in the system.

Re-Examination of the System

At this step complex systems theories are applied. The application of complex systems theories should provide us with a different understanding of system behaviour.

Comparisons

These interpretations, both the subsystem models and the CST applications, are brought into the real world and set against the perceptions of what exists there. This could be done either in collaboration with stakeholders or with other tools such as GIS and remote sensing. The purpose of the comparison is in part to generate a debate with concerned people in the region which will later aid in defining possible changes which are both desirable and feasible.

Change, Action and Monitoring

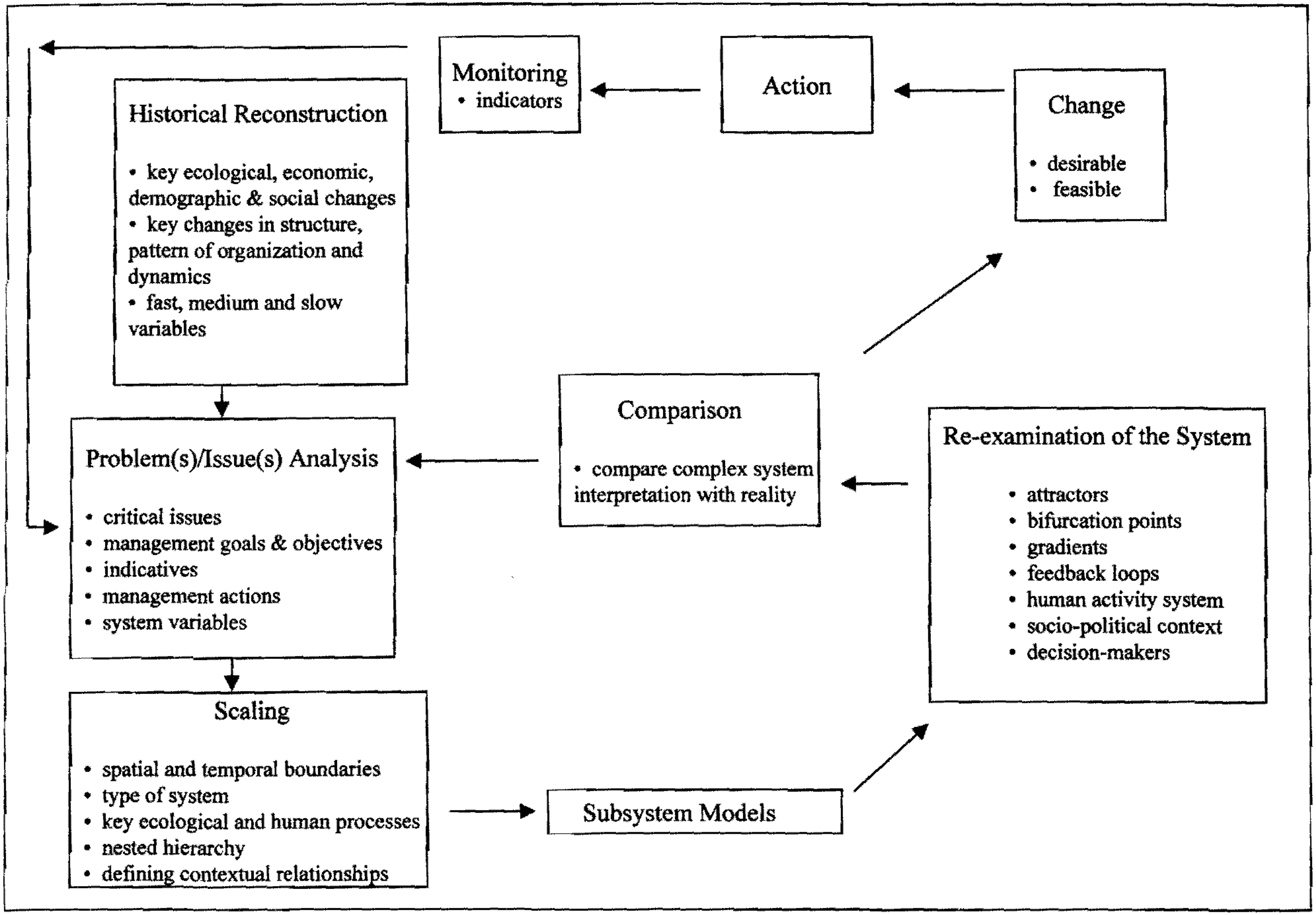
These later steps are driven primarily by the stakeholders. Once they are complete the problems and critical issues need to be reassessed.

If one wished to think of these steps in terms of researcher- community interaction, we might suggest that the scaling and historical reconstruction is best done by CIAT researchers alone; problem analysis and subsystem models by CIAT researchers in consultation with stakeholder groups; re-examination using complex systems theory is done mainly by scientists, the comparison of developed models with reality and previous models is done by both scientists and stakeholders, whereas the last few stages, from identifying possible changes, instituting and then monitoring them are mainly stakeholder driven, with facilitation and advice from scientists.

An equally important outcome of this process relates to the ability of the created or modified stakeholder institutions to sustain the process in addressing new problems. Participation in this process should be more than a "one-time" thing. We wish to create institutions in which people can, and do, continue to participate in solving their own problems long after the researchers are gone. This is the ultimate sign of success.

Finally, we emphasize that this process can be used to address many types of problems; it is both iterative and multi-faceted. There is no clear endpoint because agricultural sustainability, in an ever-changing global situation, involves not just environmental conservation and economic viability, but the creation of agricultural institutions and management practices which are responsive, adaptable, and can "learn" as they go.

Figure 1: Different Stages in the Research Process



Perceived Goals and Indicators

Gilberto C. Gallopín

I want to share with you, as background information, some results of two consultations on the major issues, goals and desirable indicators suggested for assess the degree of accomplishment of the goals. The first consultation was the Internal Workshop at CIAT (March 3, 1997) and the second was the First Workshop with the CODESU Directors, at Pucallpa (May 5, 1997). It is important to be aware that further and wider consultations are planned; the outcomes presented here have, as from now, only indicative value. It is quite possible that further consultations will bring major changes to the issues, goals and indicators.

Major Issues for the Pucallpa Agroecosystem

Note: (1) = identified at the first internal workshop (CIAT); (2) = identified in the first Pucallpa workshop; (1+2) = identified in both workshops.

Whole System:

- Perverse resilience (contagious unsustainability?)(1)
- Road system as organizing principle (1)
- River system as organizing principle (1)

Agricultural:

- Degraded pastures (1)
- Increased monocropping (1)
- Efficiency of agricultural inputs (1)
- Low cattle inventory (1)
- Low genetic potential (1)
- Lack of agricultural machinery (1)
- Seed supplies (1)
- Utilization of non-traditional crops and agroindustries (e.g. Uña de gato, camu-camu - potential uses of biodiversity) (1)
- Weeds (1)
- Soil fragility and low fertility (2)
- Lack of appropriate agricultural technology (2)
- Irreversible loss of soil/land productivity (3)

Fisheries

- Depletion and degradation of fishing stocks (1+2)
- Pollution of breeding fish grounds and critical habitats (potential; Iniría, narcotraffick) (1+2)
- Scarcity of information about ornamental and subsistence fishery (2)
- Loss of fish biodiversity due to fishing (2)

Ecological:

- Deforestation (1+2)
- Increased fragmentation (1)
- Increased percentage of secondary growth (1)

- Impacts of coca on biodiversity (1)
- Impacts of coca on deforestation (2)
- River pollution (narcotraffick) (1+2)
- Impacts of selective logging (1)
- Lack of inventory or information on biodiversity (1)
- Impacts of activities in floodplain on rivers (1)
- Environmental impact of the exploitation of natural gas (2)

ECONOMIC:

- Transport costs (1)
- Labor and capital scarcity (1)
- Sudden foreign investment and inflow (e.g., DEA) (1)
- No extension services (1)
- Coca - economic impacts (1)
- Unreliable markets, price fluctuations (1+2)
- Extractive and absentee forestry system - little reinvestment in local economy (1)
- Net economic outflow from region/ Net export of resources and benefits (at regional and national level) (1+2)
- Undervalued land prices (because of guerilla, etc.)
- Lack of access to credit (because lack of windows for small loans)

HEALTH:

- Human health problems (maybe) (1)
- Human health deterioration due to environmental degradation (2)
- Water quality (1)
- Urban air pollution (1)
- Lack of sewerage facilities (1)
- Medical uses of biodiversity (1)

SOCIAL AND DEMOGRAPHIC:

- Coca - social impacts (e.g. coca cities)
- Urban unemployment
- Rural to urban migration - social problems (e.g. out migration of youth to Pucallca)
- Urban poverty (no clear problem of rural poverty) (1+2)
- Extractivistic bias (negative attitude towards conservation) (2)
- Widening of the income gap (at the regional, national and international levels) (2)
- Lack of basic services (drinking water, education, health) (2)

INSTITUTIONAL:

- Institutional instability
- Lack of policy continuity
- No land monitoring agency
- Weakness and fragmentation of the environmental regulations (2)
- Lack of environmental content in the educational policies (2)
- Scarcity of policy instruments at the regional level (2)

POLITICAL:

- Power structure (e.g. concentrated power of timber industry) (1)
- Geopolitical context - Amazon seen as important source of development for nation (1)

Science and Technology

- Unreliability of the statistics (2)
- Dominance of the productionist approach to research (2)

Major determinants/conditioning factors (or drivers)

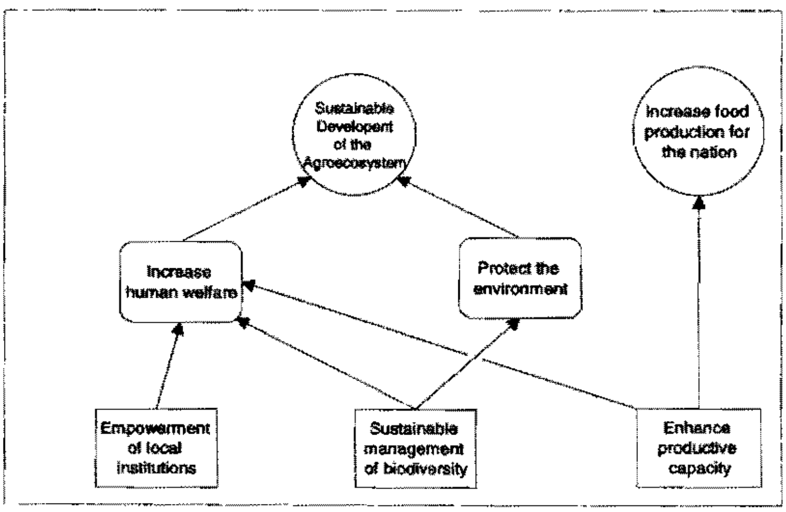
(Note: discussed only at the Pucallpa workshop)

- Quantity and skills of colonists (mostly of Andean origin); cultural and productive tradition (an ambivalent factor)
- Volume and variety of the supply of natural resources
- National policies for evaluation of natural resources
- Lack of participation (anomia?) of the civil society (an effect from terrorism?)
- Participation potential of the civil society (Pucallpazo)
- Institutions

GOALS

Note: the indicators are based on the first CIAT workshop and the first Pucallpa workshop; some have been modified. In particular, the policy fostering the Ucayali region as the food basquet for Peru has been abandoned during the present government.

For the present purposes, "agriculture" includes crop cultivation, ranching, and forestry.
"Resource" is a generic term including agricultural land, forest stock, and fish stock.



Indicators of of Goals **Accomplishment**

Goal 1. Enhance Productive Capacity

- *Total agricultural production (volume and value)* f(productivity, resource volume)

- *Productivity (total and per factor; in volume and value)*
  f(resource quality, inputs, technology, prices)

- *Land under production*
  f(total available land, land colonization rate, land abandonment/degradation rate)

- *Ratio productive/abandoned land*
  f(land under production, abandoned land)

- *Agricultural diversification*
  f(habitat diversity, producer's objective functions, existence of markets, access to markets)

- *Fish production (volume and value)*
  f(fishery productivity, fishing effort, fish stock)

- *Fishery productivity (volume and value)*
  f(catch per unit effort, total effort, prices)

- *Fish recruitment rate*
  f(fish stock, health of the aquatic ecosystems, fish harvest)

- *Fish species composition*
  f(habitat characteristics, selective harvest)

Goal 2: Increased food production for the Nation

- *Total regional food production*
  f(agricultural productivity, resource volume -land under food crops)

- *Ratio of regional to national food production*
  f(regional food production, national food production)

Goal 3: Protect the environment

- *Greenhouse gases emissions*
  f(area used, land cover, land use technology)

- *Proportion of degraded land*
  f(land quality -or fragility-, land use technology, land under production, total land available)

- *Proportion of land with native vegetation*
  f(land colonization rate, land use technology, initial stock of land with native vegetation, total land area)

- *Deforestation/reforestation ratio*
  f(deforestation rate, reforestation rate)

- *Percentage of protected areas (within specified ecosystems)*
  f(total area, area under production, degraded lands, ecosystem diversity, environmental laws and their enforcement, pressures for production)

- *Mismatch between actual and optimal land use* f(optimal land use, actual land use)

- *Changes in species composition of indicator species*
  f(natural ecological dynamics, land use, water pollution)

- *Indicators of water pollution*
  f(size of human settlements, technology of domestic waste processing, volume of industries, type of industries, industrial technology, water volume/flow)

- *Indicators of aquatic ecosystem health*
  f(ecosystem type, water pollution, fishing pressure)

Goal 4: Sustainable management of biodiversity

- *Proportion of native species with market value*
  f(total number of species, number of species with market value, technology of resource use, volume of resource used)

- *Number of non-traditional species being utilized*
  f(total number of non-traditional species, market- or use-value of non-traditional species, availability of technology, relative profitability of other uses)

- *Habitat loss of wild species*
  f(habitat diversity, habitat sizes, volume of resource use, technology of resource use, pollution)

- *Other indicators of sustainable management (?)*
  f(??)

Goal 5: Increase human welfare

- *Child mortality*
  f(nutrition, education, health, environmental conditions, access to medical services)

- *Average income*
  f(total regional income, total regional population)

- *Income distribution*
  f(employment, tax and reallocation systems, social structure, power structure, ?)

- *Capital accumulation*
  f(capital investments, capital depreciation)

- *Poverty level*
  f(income distribution, total income, social and power structure, education & skills, resource degradation, ?)

- *Unemployment*
  f(labor supply, labor demand)

- *Morbidity (diarrheal, respiratory)*
  f(same as for child mortality)

- *Satisfaction (suicide rates)*
  f(living conditions, cultural and psychological factors)

- *Crime*
  f(regulatory and enforcement systems, social structure, poverty level, community health)

- *Social support networks -community health*
  f(social structure, culture, enabling systems, power distribution)

Goal 6: Empowerment of local institutions

- *Local market versus central government determination of prices of agricultural produce (ratio)*
  f(strength of local markets, national political system, governmental application of instruments, ?)

- *Dependency ratio: ratio of regional economic product to the total value of imports and exports*
  f(regional production capacity, extra regional markets, national and regional policies, ?)

- *Proportion of credit from intra-regional banks to credit from extra-regional banks*
  f(banking regulations, volume and diversity of intra-regional banks, national and regional policies)

- *Percent of firms owned locally to firms owned extra-regionally*
  f(power structure, regulations, regional productive capacity, time since establishment of the firms, ?)

- *Percent of public services paid for by the local governments*
  f(national and regional/local policies, regional productive capacity)

- *Changes in volume of membership of local institutions*
  f(number of local institutions, culture, social structure, time since establishment of local institutions, perception of usefulness of local institutions, perception of usefulness of extra-regional institutions)

Workshop Discussions

In the workshop discussions we set out to develop a CST interpretation of the case study using the basic concepts already explained in the seminar and further refined in the panel session. The goal was to construct a conceptual "model" (not in the quantitative sense) of Pucallpa/Ucayali with CST and identify the most critical guiding questions, hypotheses and metaphors that will help us better understand the key processes and dynamics of the system. In addition we wished to initially outline the skeleton of a framework, that can then be further modified and tested in Pucallpa. This framework is intended to provide a guide for agricultural research in messy complex situations such as those that present themselves in the region.

To begin, the research process presented earlier by Tamsyn Murray, was altered. The revised process is shown below (See Figure 1b). The main difference involved the clarification of the scaling step. It was recognized that prior to the development of subsystem models and more sectoral analysis, it was imperative that a broad conceptual model of the system of interest was defined. This would include more than just scaling. For example the type of system, key processes, human and ecological, as well as the defining contextual relationships, must be identified. More specifically, the system or state variables that have to be included in order to fully comprehend the dynamics of the system, require identification. This is a critical task as incorrect identification of variables will result in invalid models and flawed understanding in the future.

Once we had identified the importance of the building of the conceptual model we started the process of describing the system. As with any holistic system approach, one of the most critical issues is what to include and what to leave out. Despite our common understanding of CST, there was some disagreement of the most appropriate method to use to build the conceptual model. One group felt that it was necessary first to outline the goals and values of the different groups of stakeholders in the system, in order then to determine the variables of interest. This was felt to be a critical step as the perspective taken, for example, a private logging company or a subsistence fisherman represent very different interests and would naturally define different variables to be measured. In addition this group described each stakeholder group within their ecological setting and thus outlined the corresponding biophysical constraints.

Analysis of Stakeholders

Table 1 is the result of discussions by the first group of participants. They set about identifying the different groups of stakeholders and their corresponding values and goals. In addition they described their environmental setting, the types of activities and products resulting, and the ecosystem affected. This highlights the diversity of social actors and the need to first take into account the type of actor before describing the system in which they operate. Goals were described for stakeholders at the household level. In addition regional, national and global goals were identified for those working in Ucayali area.

Figure 1b (revised): Different Stages in the Research Process

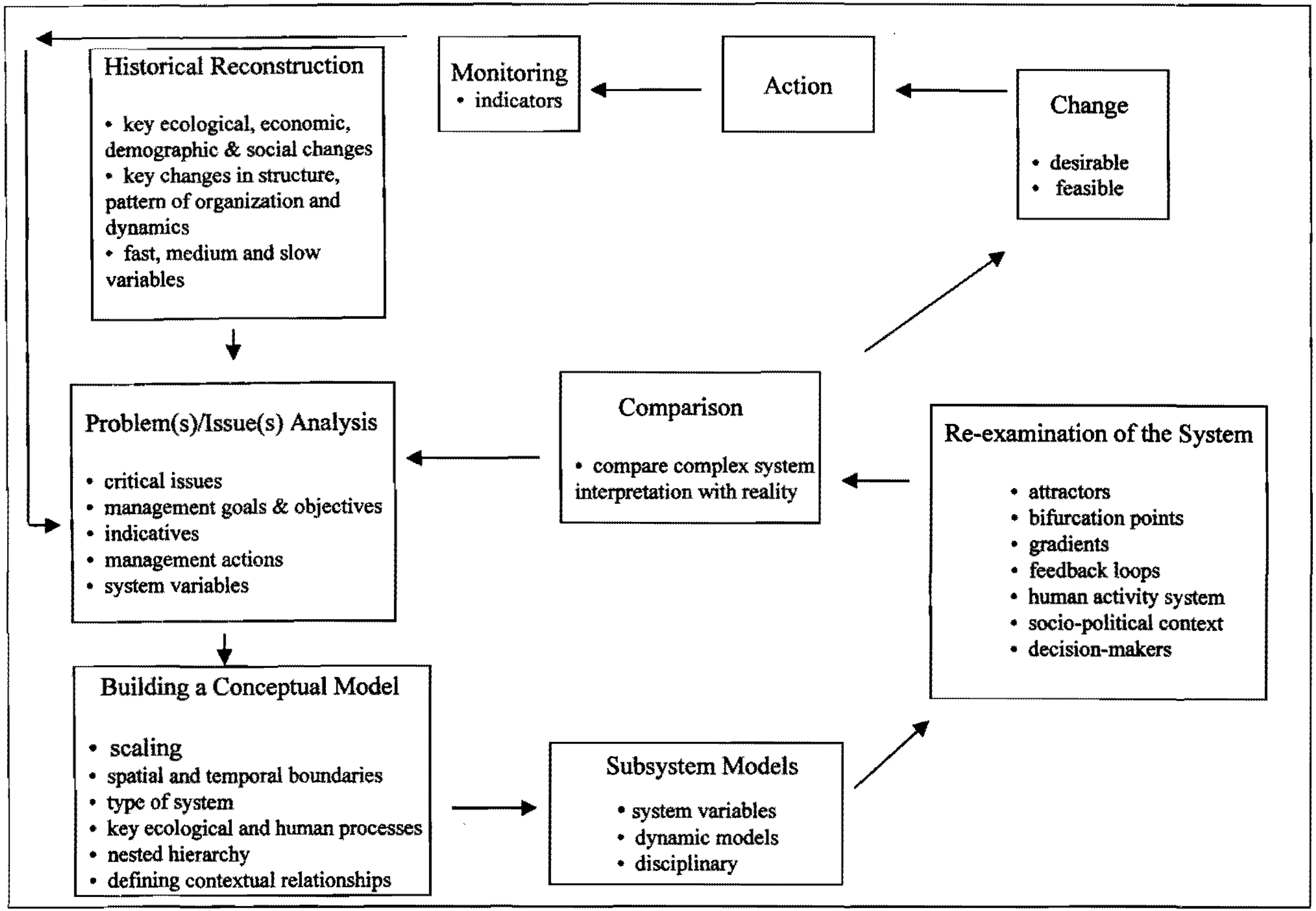


Table 1: Household Level[3]

VALUES		GOALS		PRODUCTS	ACTIVITY/ IDENTITY	RESIDENCE	ECOSYSTEM AFFECTED
Concern for future of their activity	**Will to change their status**	**Maximize Income**	**Minimize Risk**				
+++	++++	Coca price Increased exports	stable prices	Slash & burn mix (SBM) Coca Oil palm Fruits	S&B agriculture	Uplands	Upland forests
+++	+	rebuild herds	redundant herds	Beef Cassava	Cattle production	Along roads, uplands	Upland forests
+++	+++	high prices	stable production process	Bananas Fish Softwood SBM	Riverine colonists	Along rivers	Riverine comple (lowlands, river lakes, restingas
+++	++++	more tourists	stable boundary conditions	Fish Bananas Handicrafts SBM	Riverine Indians	Along rivers	Riverine comple
++	+++	increase share of revenues	stable sociopolitical environment	Hardwood timber Lesser value timber	Small timber extractors	City (Pucallpa)	Lowland and upland forests
-	-	decrease structural costs increase prices	improve conditions for long-term operations	Hardwood timber	Large timber extractors	City (Lima)	Lowland and upland forest
-	++++	Urban dream (UD): Low food prices, empowerment. more security, better services Get a job	UD		Unemployed	City (Pucallpa)	All
-	+++	UD Improve job	UD Keep job	Low-qualification services Clandestine industrial products	Under-employed	City (Pucallpa)	All
++	++	UD Higher wages	UD Better work conditions Safety on job	Lumber wood Tiles Plywood	Timber industry employed	City (Pucallpa)	All
+	++	UD Higher wages	UD Better work conditions Safety on job	Policy Technical support	Bureaucracy	City (Pucallpa)	All
		UD	UD	Services	Commerce	City (Pucallpa)	All
		UD	UD	Services	Services	City (Pucallpa)	All
-?	-	UD Higher coca prices	UD Less law enforcement	Cocaine	Drug dealing	City (Pucallpa, Lima, COLOMBI A)	All

[3] ... incomplete groups: Urban dwellers
UD = Urban dream
+ low; ++ medium; +++ high; ++++ very high

Goals at the Regional Government Level (for the Ucayali region):

- Increase regional GDP
- Increase funds from central government (larger share of local money)
- Keep and enhance power

Goals at the Central Government Level (for the Ucayali region):

- Defeat and control guerrillas
- Decrease and control coca production
- Increase food production (for export and self-sufficiency)
- Increase GNP

Goals at the Global Level (for the Ucayali region):

- Protect biodiversity
- Decrease and control deforestation (decrease greenhouse gas emissions)
- Decrease coca production

Influence Diagrams

The second group, viewed more as the "theorists", wished to identify the main components of the system and the nature of their relationships. As shown below in Figure 2 and 3, different components or activities can be seen as positively or negatively correlated. In other words in a positive correlation if one variable increases or decreases, so too does the other increase or decrease respectively. A negative correlation implies that as one variable increases the other decreases (They move in opposite directions). It is important to note that the change in the variable may refer to either a change in quantity, ie. Area of activity, or quality, ie. Productivity.

Figure 2 differentiates landscape integrity from human well-being and identifies the different variables that influence each one. Obviously there is some overlap as the same variables will affect the ecological and human dimensions. Such diagrams are important is highlighting such interrelationships. Figure 3 is less generic and attempts to tease out the key relationsips in the Ucayali agroecosystem. For the sake of clarity we have once again separated humans and their surroundings as the impacts of resource use are more evident. We described the human dimension as comprising of capital ie. Markets, the civil state and society or community. In terms of resources we identified forest, agricultural land and aquatic systems. Coca and cattle are identified separately mainly due to their significance and importance in influencing system dynamics.

It is important to preface this figure and the following description with a word of caution. The relationships described here were based on the expertise of those participating in the workshop. It therefore represents their views and is thus a product of the group selected. If such a group was different it is quite likely that the figures and described relationships would not be the same. In addition this raises the important point that there is in fact much dispute over a number of issues eg. Land abandonment, degradation of the fisheries, the environmental impact of coca etc., and in many cases inadequate information available to resolve such disputes.

To briefly outline the key relationships, presented below are the components that are negatively correlated include:

(i) Forests and agricultural land - obviously as more land is cleared there is less forest
(ii) Forests and capital - as markets increase and strengthen the forest is further exploited
(iii) Cattle and agricultural land - as cattle numbers increase the productivity of the land decreases

(iv) Coca and cattle - as coca production increases and as has been shown in the past, so too does social violence and land abandonment, the number of cattle numbers declines
(v) Coca and forests - as coca production increases more land is cleared, in addition coca processing pollutes the environment
(vi) Society, in this case the elite and forests - there is evidence that the majority of those responsible for commercial logging are wealthy private companies based in Lima - as they gain wealth and more technology so does the forest deteriorate
(vii) Society (poor) and aquatic systems – as the number of poor people increase they place increasing pressure on the fisheries resources.
(viii) Society (elite and therefore the commercial fishermen) and aquatic systems – as the commercial fishery increases in size and ability to catch fish more efficiently, aquatic systems are increasingly stressed.
(ix) Society (poor) and forests – as the number of colonists increase the forests are increasingly undermined. This occurs through both selective logging and slash and burn agriculture.

Positively correlated components include:

(i) Forests and aquatic systems – the health of the forests and rivers are inextricably linked and any deterioration in one will cause deterioration in the other.
(ii) Coca and agricultural land – as the level of production of coca has increased so too as the amount of land cultivated.
(iii) Military and coca – with the increase in coca production and the greater prevalence of terrorism, specifically the sonderos, the military presence has also increased.
(iv) Military and black economy – as the presence of the military is heightened, the size of the black economy grows.
(v) Capital and cattle – as the capital markets become stronger, the number of cattle increase.

Figure 2: Influence diagram highlighting the different components and their affect on landscape integrity and human well-being in the Ucayali region

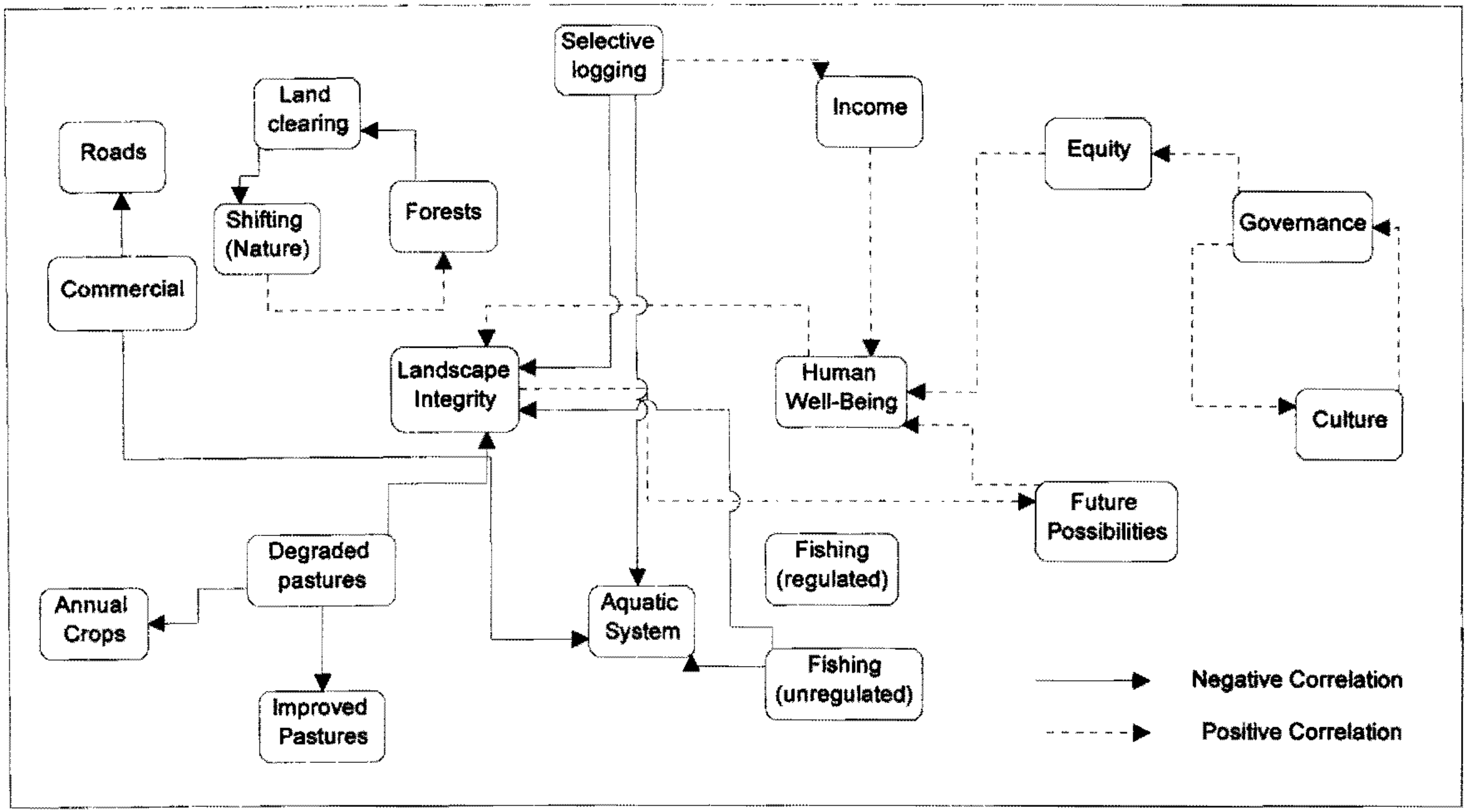
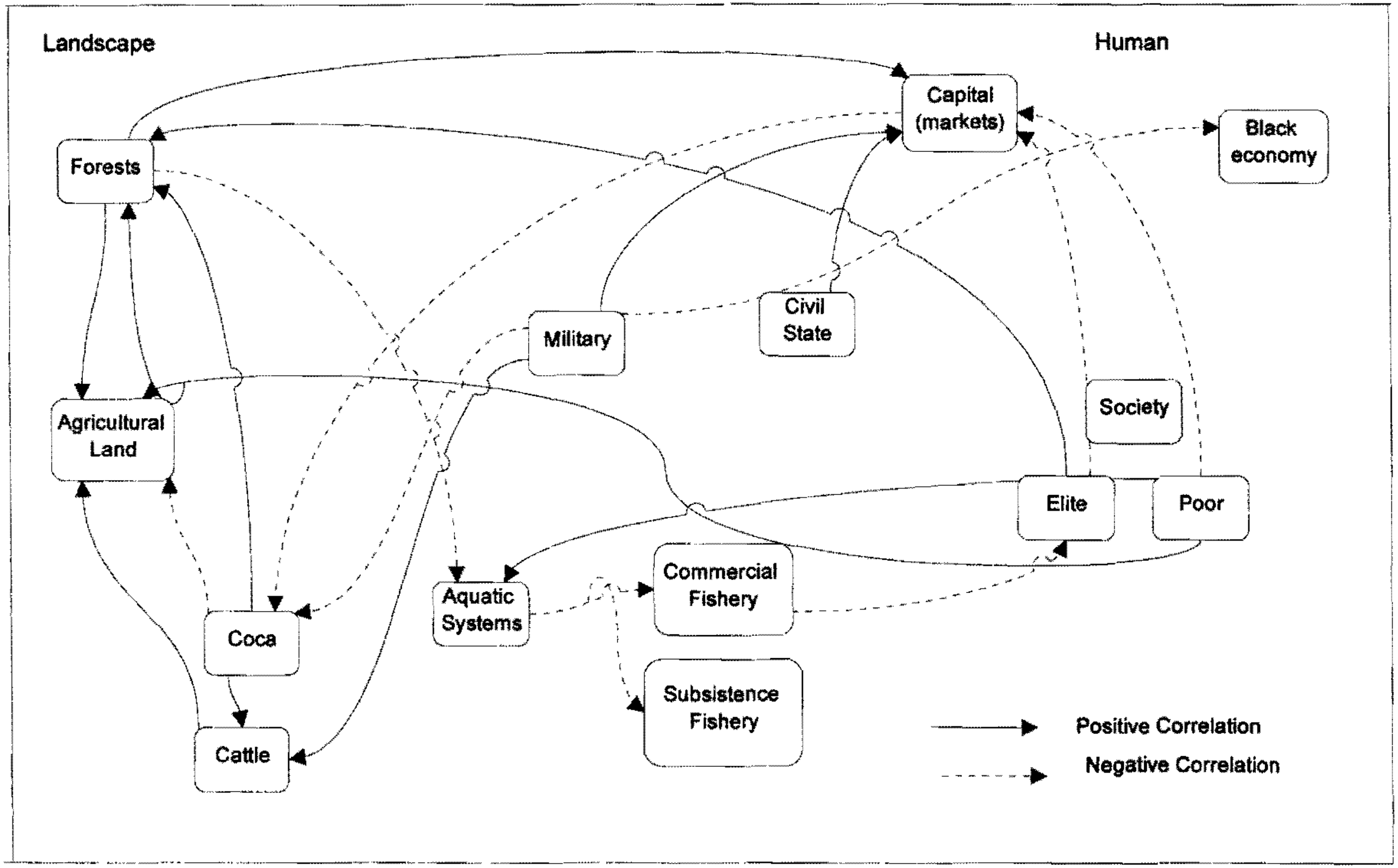


Figure 3: Influence diagram highlighting the key components and the relationships among them in the Ucayali region



AGROECOSYSTEM DEVELOPMENT IN UCAYALI, PERUVIAN AMAZON.
A CATASTROPHE THEORY REPRESENTATION

Gallopín, G.C, J. Kay, D. Waltner-Toews, E.Raez Luna and T. Murray
1 September 1997

In the most general terms, a state is "any well defined condition that can be recognized if it occurs again" (Ashby 1956 p. 25). When applied to a system, the state is described by a list of the values taken at a given moment by each of the variables representing the system.

Dynamical systems are members of very general class of systems whose state change through time, as a function of its previous state and, in general, also of some parameters which may be constants or variables representing an influence from the environment of the system.

Dynamical systems are basically described in terms of a "playing field" or generalized space where the motion of the system takes place and a rule telling the system where to go next from wherever state the system is now -Casti 1994) may exhibit three basic types of attractors (states or sets of states where the system's states tends to go): fixed points, periodic orbits and "strange attractors".

The name "*attractor*" refers to the property that, if the state of the system is slightly moved away from the attractor, it will tend to come back to it. A "*repeller*" is a state or set of states such that, if the system is there, it will stay there; however, if the system is moved away even slightly from the repeller, it will tend to move further away. A *fixed point* is a state of the system at which the rate of change in the state is zero; it may be an attractor (stable fixed point) or a repeller (unstable fixed point). By contrast, periodic orbits and strange attractors represent sets of states in permanent change.

Catastrophe theory (actually elementary catastrophe theory, the one best developed) deals with only those systems whose attractors are fixed points. For such systems, each value of the input parameters determines (at least) one fixed-point attractor to which the system will tend to move. In catastrophe theory the state of the system is viewed as the output or response and the parameters as the inputs[1]. Conceptually, this is equivalent to observe the performance of a system by monitoring the steady state value of its output (variable of interest) as a function of the input quantities (parameters); for every value of the inputs, the output tends to move to a particular level (the fixed-point attractor). The fixed point attractor can be visualized as a point in the space of states of the system, and the set of all fixed points (one for each value of the inputs) can be seen as a surface. In most cases, if the inputs are changed slightly, the output also shifts only slightly. But occasionally we will encounter a combination of input values such that if we change them only a small amount, the corresponding output will shift discontinuously to a very different value. Such a value of the inputs is called a *catastrophe point* (Casti 1994). These catastrophe points arise at just those input levels where one fixed point bifurcates into several (or where several fixed points coalesce into one) . And the jump discontinuity is a reflection of the system "deciding" to move from the region of one attractor to that of another. Catastrophe theory shows that there are only a small number of non equivalent ways in which these jumps can take place, and it provides a standard picture for each of the different geometries that the surface of attractors can display.

In other words, as we run through all possible parameters values, a surface is generated, each of whose points is a fixed point (either an attractor of a repeller) of the dynamical process. A *catastrophe* as defined by René Thom (the French mathematician who founded catastrophe theory) corresponds to those parameter values where the fixed point shifts from being an attractor to becoming a repeller. This is how a small change in something (a parameter value) can lead to a sudden, discontinuous change in something else (the particular fixed-point to which the system is attracted -Casti 1994).

The generic geometry of the relation between attractors and parameters values for any system having two

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[1] For instance, $dx/dt = x^3 + \lambda x + \mu$ represents a system for which the rate of change through time of its state (dx/dt) depends on the current value of the state (x) and two parameters λ and μ. Each value of the parameters determines a different fixed point (the value of x for which $dx/dt = 0$; this value is different for each set of values of the parameters).

parameters (inputs) and one response (output) is depicted in Figure 1. This is called the cusp catastrophe (the simplest of the elementary catastrophes after the fold catastrophe[2]).

Thom proved that there exist seven elementary catastrophes for systems described by up to four parameters and up to two outputs (Thom 1972).

This kind of representation might be useful to help thinking about possible mechanisms and explanations for the case-study in the Ucayali region of the Peruvian Amazon. In our current state of knowledge, the main features of the situation can be summarized as:

- Tropical agricultural frontier area with external incentives for colonization

- Continued immigration, non-rooted social structure, no historical identity

- Stagnant economy, historically resilient to perturbations (different policies, "booms" of prices of products, violence waves)

- Locally unsustainable use of natural resources, "destroy and move" mode, feeding on a huge accumulated natural capital (which could last 20-30 years), represented by the tropical forests and freshwater ecosystems.

- The major organizing principles or shaping forces of land use/occupation seem to be 1) the river system and 2) the road system. Both of them are critical in providing human access to the natural resources and to facilitate export of the produce.

It is not unnatural to consider the pace of **economic activity** (EA) as a rate variable (e.g. GDP, income) describing the state of a system controlled by two parameters: the available natural resources (forests, agricultural and grazing land, perhaps also fisheries in this case) and accumulated wealth. The concept of **wealth** (W) as used here is not just capital, but it related to quality. In a sense, wealth could be taken as useful capital (either economic or social), or the capacity of the accumulated stock to do work. This broad conception should be kept in mind, although in some cases one could use the conventional measure of capital (or, in the social side, human resources (World Bank 1995- or societal cohesion) as a first approximation. Economic activity is a rate, wealth and available natural resources (ANR) are stocks viewed here as parameters. Putting this in another way, W and ANR are inputs, and EA is the output of this very simplified system. The implication of this formulation is that $dEA/dt = f(EA, ANR, W)$, and for each pair of values (ANR, W) at least a fixed point at which $dEA/dt = 0$ is defined[3].

Technology may affect both the availability of natural resources (by allowing the use of new resources, by increasing access to them, by helping resource renewal, etc.) and it may affect the ratio EA/W, increasing economic productivity of wealth, in some sense. This effect results in that for a given level of W, a higher EA is obtained.

The concept of **available natural resources** is not intrinsically obvious and requires explanation. By ANR we mean here the natural resources that can be immediately utilized[4], and is a function not only of the abundance of the resources (of which, at least in the case of forests, there is an "unlimited" supply -i.e., a supply that could last at least 30-40 years at the current rate of exploitation), but also of their availability in terms of people being able to reach the resource through roads or rivers, and of they having the means to use them. Opening new roads increases the ANR even if the total volume is unchanged. Therefore, overexploitation of the resources may be compensated (at least temporarily) by additional road

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[2] The fold catastrophe is the only catastrophe possible for systems having one input and one output.

[3] Note this is a very simplified formulation, neglecting for instance, the influence of EA upon W and ANR.

[4] This concept is somehow analogous to that of available energy (Moran 1995, Ch.7)

penetration, thus maintaining or even increasing ANR.

The representation of this idealized case in the form of a cusp catastrophe appears in Figure 2. The discussion will focus primarily on forest resources.

The lower surface represents the projection of the upper (folded) surface onto the plane determined by the values of the two parameters W and ANR. Under this projection, the two fold lines of the upper surface map into the two branches of the spikelike curve of the lower surface. Note that the fold is not symmetric, reflecting the hypothesis that in the case of Ucayali, the higher W is, the lower the value of ANR at which a catastrophic jump from the upper stable points to the lower stable points is possible (and conversely, a jump from the lower stable points to the upper stable points due, e.g., to a shift in technology or in products exploited).

Figure 3a depicts a possible trajectory followed by the state of the system in the folded surface.

The situation represented is that more and more resources are made available by opening roads or developing river transportation. This occurs at low levels of W (because EA is initially low and/or most of the wealth produced by the EA is exported out of the region to Lima).

If ANR gradually increases (because of opening of new roads or improved river transportation -in Ucayali the total volume of natural resources is not increasing-) then EA also increases (increasing exploitation), following the path from A to B in Figure 3b.

Hypothetically, an increase of ANR without increasing W (thus keeping the path near the front border of the plane, as shown in Figure 3a) will eventually result in a sudden increase in the steady state value of EA (e.g. due to a technological shift or the emergence of an economy of scale or a new economic activity). The state of the system (here represented by EA) moves suddenly from B to C. If the pace (and nature) of economic activity does result in a decrease of ANR, then the exhaustion of the ANR would begin to inhibit EA and both EA and ANR would diminish (segment C to D in Figure 3b). Eventually a threshold of ANR would be reached and the ANR will not be able to sustain the type of activities any more, resulting in a crash of EA to a low level (from D to E).

Figure 3b also illustrates the phenomenon of *hysteresis* exhibited by the system described here. In brief, hysteresis implies that the specific trajectory or path of states followed by a system depends on the system's past history. If the value of ANR is gradually decreased from the one corresponding to the projection of C into the ANR axis, towards the value corresponding to D, and then EA drops into the lower branch A-B, the system will not follow the same path to return to the upper branch if ANR is now increased to the value it had before the drop. Instead, it will be necessary to increase ANR until it reaches the level corresponding to B, and only at that point the system jumps to the upper branch.

A conjecture we are making is that the discontinuous jump and the resulting hysteresis effect will be exacerbated by the lack of accumulated wealth. The more wealth in the system the smaller the catastrophic jump (Figure 4). At still higher values of wealth the fold vanishes and a smooth path remains as the only possibility (Figure 5). Therefore, even if resource availability decreases, the system is not exposed to sudden changes.

Note that even if W increases along the path, the crash is still possible (albeit of smaller magnitude) unless the rate of increase in W is fast enough to circumvent the fold as shown in Figure 6.

The description in terms of the folded surface is based on the assumption that changes in the values of the parameters (inputs) affect the system's response (outputs). However, at least in the case we are considering, the system's output is likely to affect the values of the parameters (e.g., the pace of economic activity may affect the accessibility of natural resources[5], and certainly it may affect the accumulation of wealth)[6]. What would be the implications of those feedbacks in terms of the representation we are using? Essentially, it will mean that the surface itself will be changing in time, stretching, contracting, with new bumps and folds appearing, in a way very difficult to predict. All of this shows that the use of this representation is a strong simplification of the problem, justified only if it brings useful insights and interesting and fruitful new types of questions about the development process and the relationships between economy and natural resources in agroecosystems.

A note of caution is in order here. Catastrophe theory has proven its theoretical and practical utility in a number of physically existing systems (Casti 1994) and it has been used (and debated) in fields from the heartbeat to economics, politics and psychology (Zeeman 1977, Postle 1980, Tu 1994).

However, its *rigorous* application requires to have a known mathematical formula describing the underlying process. This is certainly not the case for agroecosystems, and many social scientists would argue that such a representation is not even possible in principle. Therefore, it is important to emphasize that we are using catastrophe theory for describing (and, hopefully, contribute to explaining) the Ucayali case in what Casti (1994) termed the "metaphysical way", as a metaphor to identify guiding questions, or a qualitative mathematical language (Postle 1980) to describe discontinuities arising from continuous processes in agroecosystems. Casti (1994 p.79) provides a cogent description of the assumptions imbedded in the use of catastrophe theory in the metaphysical way.

The case discussed here (one output, two parameters) corresponds to the so-called *cusp catastrophe* (the simplest elementary catastrophe besides the fold catastrophe describing systems with one output and one parameter). Thom described seven elementary catastrophes of which the parabolic umbilic, representing the behavior of a system with two outputs and four parameters, is the most complex. Subsequently, four additional types have been found completing eleven elementary catastrophes for systems with up to five parameters (Tu 1994). However, as the number of dimensions (parameters plus outputs) increase, it becomes more and more difficult to visualize the surfaces representing the values of the fixed points for each combination of values of the parameters. The geometry also becomes more complex. For instance, the butterfly catastrophe becomes possible for systems with four parameters and one output. It is interesting that in this case a third mode of stable behavior emerges, above and beyond the upper and lower sheets possible with the cusp; this is a stable region of compromise behavior (Casti 1994 p.65). It is possible that more basic variables need to be taken into account in the description of the Ucayali case (even at the very rough approximation used here); population is an obvious candidate. If so more complex elementary catastrophes should be taken into account, beyond the cusp catastrophe discussed here.

If the catastrophe-theoretical representation makes any sense, a number of implications can tentatively be drawn:

1. A gradual path of successive fixed-points of the system may exist, but this implies circumventing the fold as in Figure 7a. This requires increasing W fast enough (by reinvesting within the region, by more efficient use of the natural resources, or by additional inputs -subsidies, etc.- into the region) to move to the upper surface from the back of the fold.

2. A sudden jump to higher levels of economic activity may occur as natural resources become more available (e.g. because of a change in activity). The jump may accelerate the transition to a more "modern" economy, a sort of "takeoff" effect, but also it may create the risk of a fall down. However, if the

[5] One possible mechanism is that as EA increases more resources are made accessible (e.g. because forestry exploitation moves into another areas -due to expansion of the activity or exhaustion of exploited forests- provided the rate of exhaustion of forests is not higher than the rate of expansion of the forest activities into new areas)

[6] Wealth W should depend on economic activity (rate and profitability) as well as "imports" such as subsidies and "exports" such as wealth channeled outside the regional system.

new EA generates significantly more W (or if after the jump, a deliberate strategy of reinvestment or cutting off the drainage of W from the region is established) then the fold may be avoided even if ANR decreases (Figure 7b).

3. The system might follow a gradual path to a high level of EA and ANR, but is W starts to decrease later on, the possibility of a crash may materialize (Figure 7c).

4. Another possibility is that, depending on the location of the current fixed-point, a gradual reduction in W could result in diverging paths where a small change could lead to widely different levels of EA (without exhibiting catastrophic behavior) as shown in Figure 7d.

The discussion so far refers to the folded surface as composed by all the fixed points of the system (attractors and repellers). The actual state of the system will lay on the surface if and only if the system is at the critical point or steady state. This will happens provided the parameters vary slowly (smoothly) in comparison with the state of the system. In other words, at each value of the parameter values, the system has enough time to reach its steady state or fixed point. If the parameters change too fast, the state of the system may not lie on the surface, but far from it, until it settles down on the surface. If the parameters keep changing fast all the time, for each value of the parameters a distribution of values for the state of the system would exist (the surface composed by the fixed points would still be there, but the distribution of actual states of the system would look like a blurred cloud above and below the surface). In other words, the system will not be at a steady state (of fixed point) but mostly at transient points, and the validity of the catastrophe theory representation would break down. Metaphorically, this situation can be interpreted as a system that is suffering a continuous and intense perturbation ("shaking" the values of its parameters or inputs). The Ucayali region and its urban center Pucallpa represent a typical example of a frontier area, with immigration and settlement expansion, and therefore in permanent change. It is open to debate whether the state of system can be looked at as being at a fixed-point (on the other hand, it is only required that EA vary in "fast" time to reach steady state relative to W and ANR, so that the latter vary in "slow" time -Tu. 1994 p.227).

This means that there are two kinds of movements of the system to be considered, The first is the slow motion of the state of the system along its fixed points (i.e. the system is always at a steady state, by the steady state itself changes slowly). The second is a transient change in the value of the state of the system. The transient change may be due to a sudden change in the value of the parameters, or to an external perturbation moving the state of the system away from the fixed point. This transient change may move the state of the system in such a way that it falls into the domain of attraction of another attractor. In the case of Ucayali, one expression of what has been called "perverse resilience" could be that despite a number of "booms" and subsidies moving the state of the system above the lower level attractor surface, the change in state is not enough to cross the repeller surface and to flip the system to the higher attractor surface, and the system (even when the possibility of moving to a higher attractor exists) falls back into the stagnant situation (low W, even at high levels of EA and ANR) as shown in Figure 8.

Some basic **research questions** that can be derived from the above analysis are:

1. Is the catastrophe theory representation inherently consistent (or compatible) with what we know about the behavior of the system (e.g. does the use of this representation imply assumptions that fundamentally contradict our general knowledge about how the system really operates?)

2. Assuming a basic contradiction does not exist, are the variables chosen to represent the simplified response and the inputs/parameters (EA, W, ANR) a reasonable selection and might they be related in the manner discussed above? Which would be the general criteria for choosing the appropriate variables? (for instance, an alternative descriptor of the system's behavior would be the changes in the quality of life of the human population of the area.)

3. What kind of empirical evidence could be used to reject or validate (even if only in a "soft" way) the metaphoric description and implications developed here?

4. Assuming it can be shown that this representation is robust and amenable to some kind of validation, what is the value added by using it? Does it lead to new theoretical or practical insights?

In terms of development strategies in the context of catastrophe theory, there seem to be four basic options: 1) to identify adequate paths to move towards the desired situation along the fixed-points surface (assuming the shape of the surface is knowable); 2) to change the location or accessibility of the critical points, e.g. "pulling" the fold away from the current path while preserving the original topological identity of the surface; 3) to impose constraints (e.g. from the higher national level) thereby blocking the system from moving into some regions of the state space (Figure 9); and 4) to change the surface itself, deliberately creating or deleting folds and shapes. This would imply establishing feedbacks connecting the output and the inputs (but the nature and strength of the feedbacks would be very difficult to identify)

Figure Captions

Figure 1. The cusp catastrophe (redrawn from Casti, 1994). *a,b* = parameters (inputs); *x* = state or output. The surface is made of all those state values that are fixed points of the system. The points lying on the fold between the upper and lower surface are unstable fixed points (repellers); all the other points on the surface are attractors. All the remaining points in the space defined by *a,b* and *x* but *not on the surface* are not fixed points (the state of the system may or may not go through them, but it will not stay there).

Figure 2. The cusp catastrophe and its projection onto the {W, ANR} plane.

Figure 3. A trajectory exhibiting two catastrophic jumps in economic activity (EA) due to changes in available natural resources (ANR), at low levels of accumulated wealth (W). Figure 3a: a three-dimensional representation of the trajectory in the attractor surface. Figure 3b: the projection in the (EA, ANR) plane. Solid lines represent stable fixed points (attractors), dashed lines represent catastrophic jumps, and the dotted line represents unstable fixed points (repellers).

Figure 4. Reduction in the size of the jump as accumulated wealth W increases.

Figure 5. Smooth trajectories at high levels of accumulated wealth W (no repellers exist in this region). Figure 5a: the full representation in three-dimensional space. Figure 5b: the projection into the (EA, ANR) plane.

Figure 6. Catastrophic drop to the lower surface because of insufficient accumulation of wealth.

Figure 7. Four development trajectories of economic activity.

Figure 8. An interpretation of Ucayali stagnation. The combined values of W and ANR maintain the system on the lower surface, and the transient changes (i.e. perturbations) in the state of the system are not large enough to allow the jump to the upper attractors.

Figure 9. An external constraint blockinf the state of the system to reach parts (back) of the surface.

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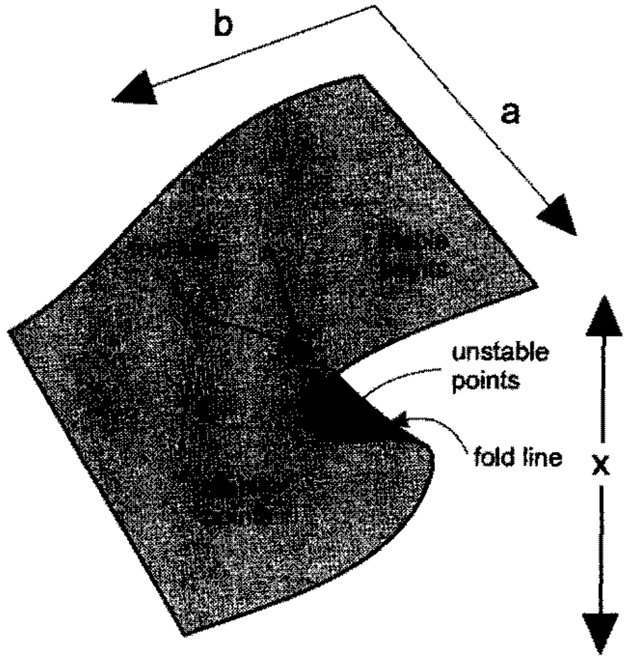


Figure 1

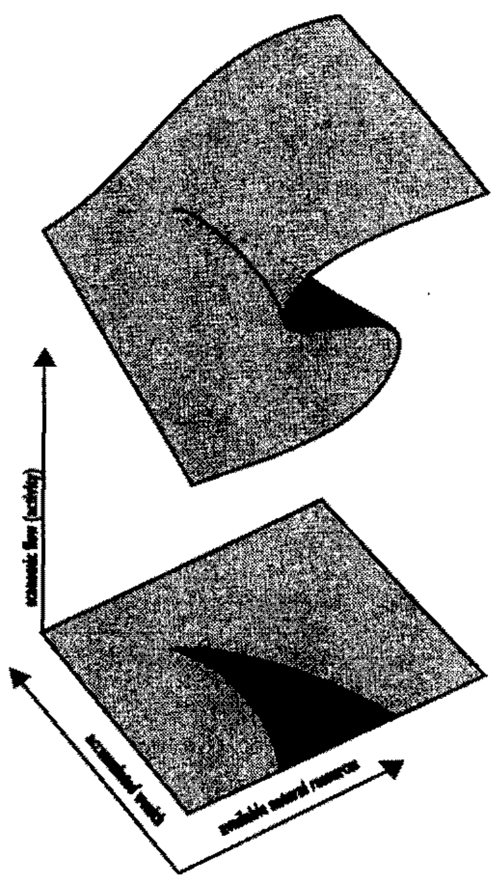
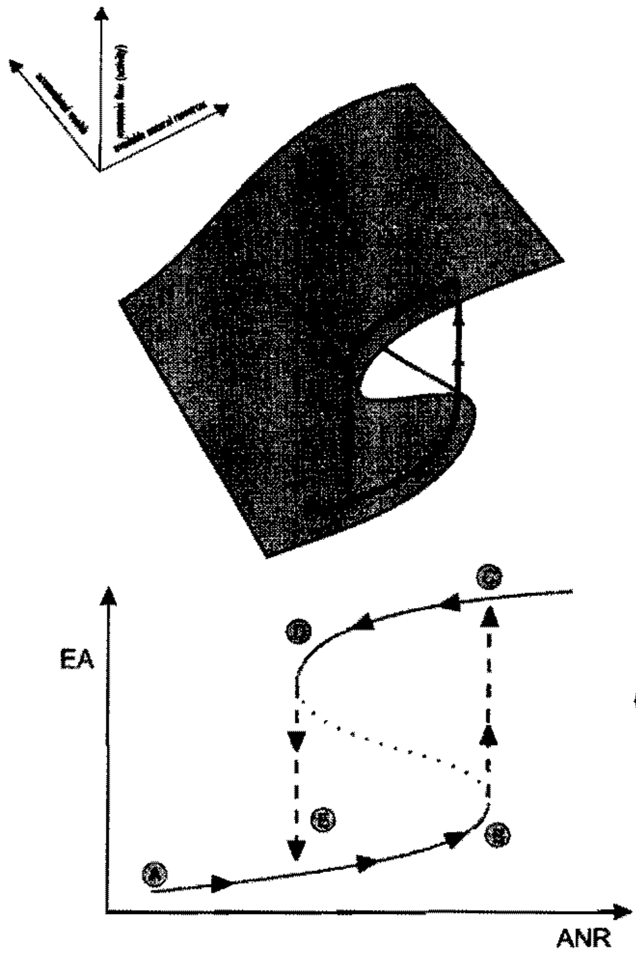


Figure 2



(a)

(b)

Figure 3

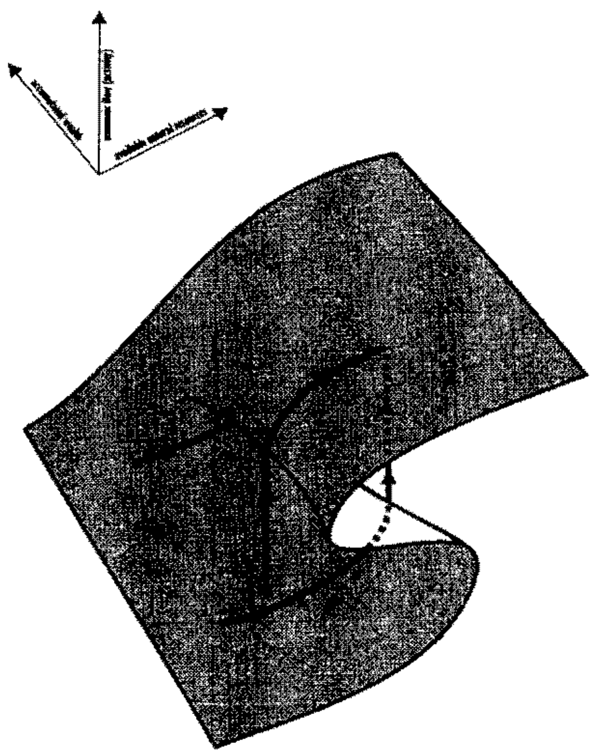
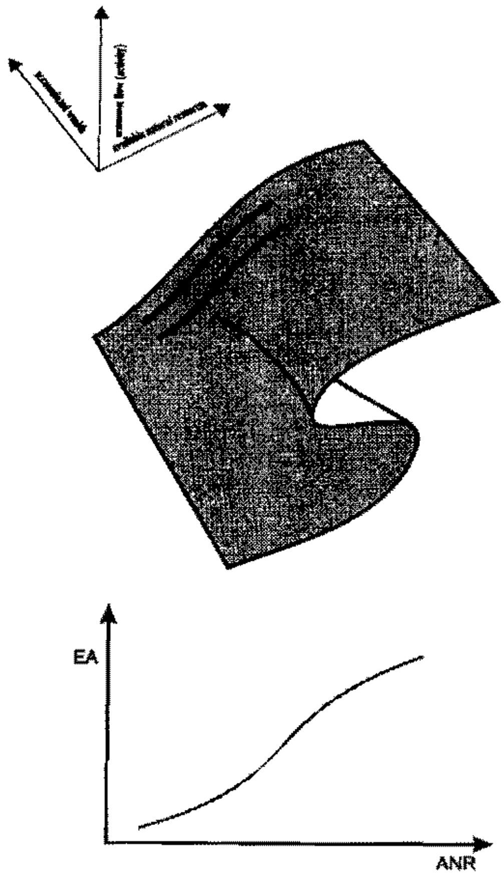


Figure 4



(a)

(b)

Figure 5

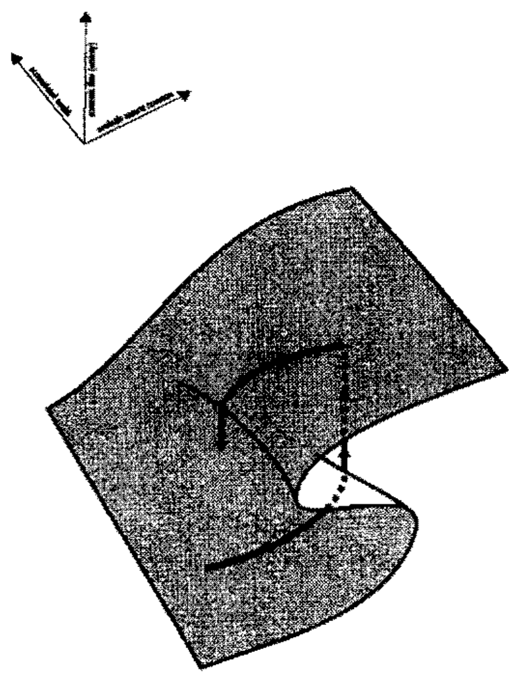


Figure 6

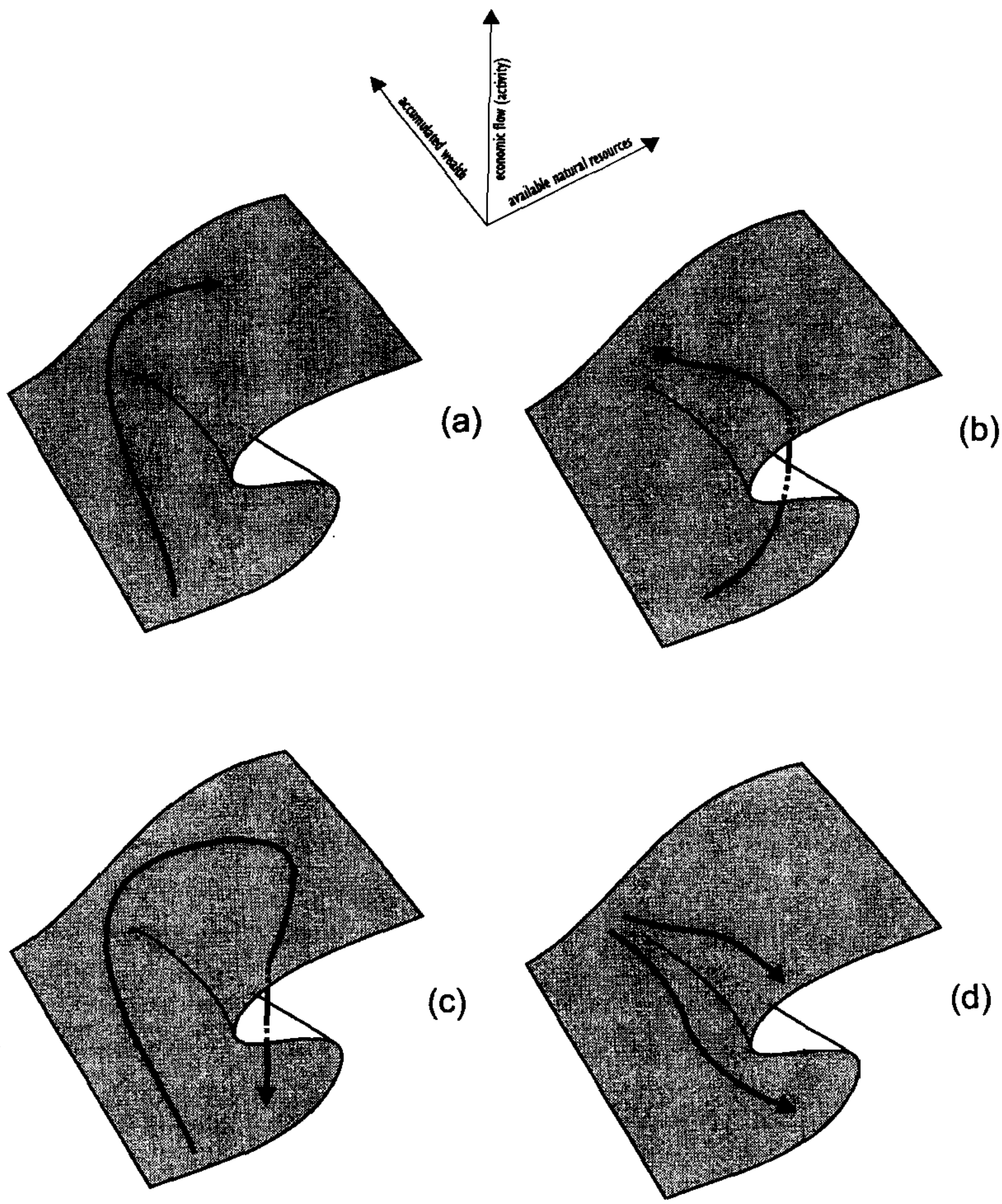

economic flow (activity)
accumulated wealth
available natural resources
(a)
(b)
(c)
(d)

Figure 7

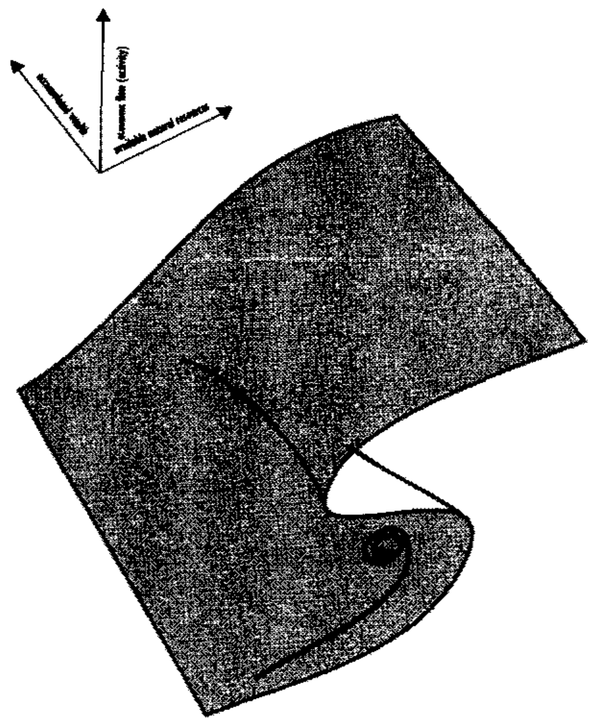


Figure 8

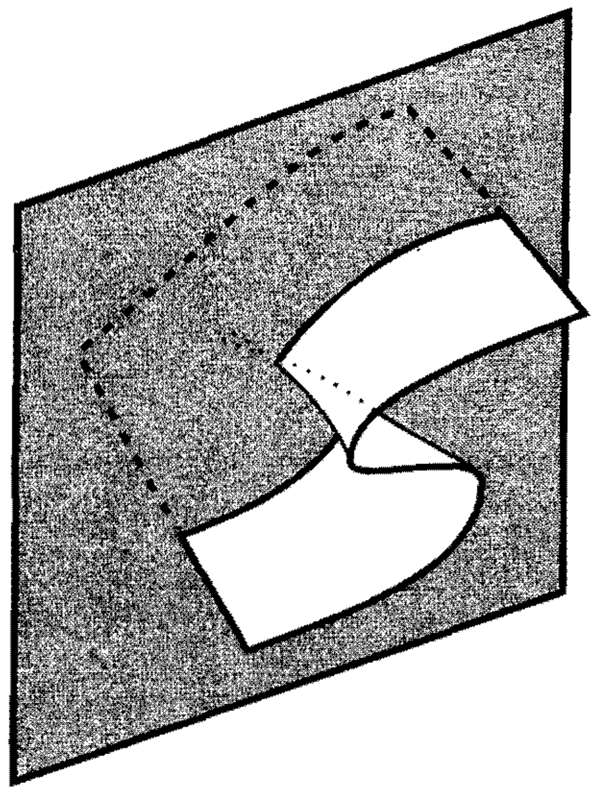


Figure 9

Research Priorities

With the new insights derived from the application of CST, we intended to identify research priorities for CIAT for the region. At present CIAT has 7 projects working in Pucallpa. The integrated conceptual framework should help in locating each project in a similar context and help identify synergistic and complementary relationships that can be exploited. We wish to clarify how data and results from one project can feed into others and how as a whole they can contribute to a more complete picture of the situation.

Below is a list of the research recommendations of the participants:

- Review other similar case studies
- How to tackle slow and fast variables
- Define the state space and state variable
- Autocatalytic research process
- Attractors and dimensionality
- Multi-criteria evaluation
- Methods of involving stakeholders
- Generic structure
- How to deal with cross-scale issues
- Explore amoeba diagrams
- Revise the research process
- How to identify the attractors
- Conflict resolution science across scales
- Explore the "Ecological footprint"concept
- Labelling the influence arrows
- Open the boxes in the influence diagrams
- How to deal with space-time issues
- Relative strengths of the relationships
- How to articulate a plurality approach
- Take areas/issues wher there is disagreement and try to solve them

This was then organized into various sections that comprise the next research activities for the project.

(i) Develop conceptual framework

- Variables and state space
- Space-time issues
- Attractors and dimensionality
- Cross-scale issues
- How to identify attractors

(ii) Enrich and refine influence diagram

- Slow-medium-fast interactions
- Relative strengths
- Labelling influence arrows
- Open boxes – expose hierarchy

(iii) Literature Review

- Similar communities
- Similar projects/participatory methods
- Conflict resolution
- Collate information on coping with trade-offs eg. Amoeba diagrams, multicriteria analysis

Simplifying it one step further:

1. Issues framework – goals at different levels
2. Conceptual models – nested frameworks and influence diagrams
3. Metaphors/hypotheses on dynamics
4. Trade-off issues
5. Specify models

a. Apply "models" to Pucallpa
b. Identification of hypotheses
c. Look for data in Pucallpa

Appendix One

OVERVIEW OF THE PROJECT

Development and Application of an Integrated Conceptual Framework to Tropical Agroecosystems Based on Complex Systems Theories: CIAT - University of Guelph Project

Prepared for the
First International Workshop of the CIAT - University of Guelph Project

May 26 - May 28 1997

Tamsyn Murray
Gilberto Gallopín
David Waltner-Toews
Ernesto Raez-Luna

Contents

Developing an Integrated Conceptual Framework to Guide Research on Agricultural Sustainability for Tropical Agroecosystems CIAT-University of Guelph Project

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Background

It is widely recognized that the problematic social, economic, environmental and productive issues facing agriculture and agricultural communities are part of a complex set of activities involving farmers, farm organizations, rural communities, national, regional and international governments and institutions. Environmental, social, and economic impacts have various kinds of repercussions not only for individual farmers where they live, but for all actors at all levels in the agroecosystem. Constraints and opportunities occur at each level in this hierarchy. These may include the nature and variety of markets, soil types and erosion, social structures and national policies. There is an increasing sense of un-ease with traditional sectoral and disciplinary approaches, and a consensus that it is important to take a broad view when trying to solve agricultural problems.

The quest for sustainable agricultural development requires integrating economic, social, cultural, political, and ecological factors. It requires the constructive articulation of the top-down approaches to development with the bottom-up or grassroots initiatives, the simultaneous consideration of the local and the global dimensions and of the way they interact and the broadening of the space and time horizons to accommodate the need for intergenerational as well as intragenerational equity.

Recently, the Consultative Group on International Agricultural Research (CGIAR) stated that "*as yet, there is no accepted research model which embraces the physical, biological and human dimensions of long term (agricultural) sustainability. Developing such a model is a goal of truly international importance*" (CGIAR 1993).

It is the goal of the CIAT-University of Guelph Project, funded by the Canadian International Development Agency, to develop such a model. Such a model will certainly be more flexible and in some aspects at least, less easy to quantify than a research model for physics or chemistry. The CGIAR was referring to a new interdisciplinary, multi-level, both site-specific and contextually meaningful , systemic approach to agricultural research, as opposed to the dominating "commodity model". A research model in this sense includes essentially a goal (agricultural sustainability), a conceptual framework, a set of procedures, and falsification criteria. The development of a holistic conceptual framework for understanding and anticipating agroecosystem dynamics and behaviour is an essential piece of a new research model. Some attempts have been made to create robust conceptual frameworks, and to identify important indicators of influential forces at all levels, in order to address real-world problems and to translate this vague unease into concrete recommendations for policy and actions (Rapport 1989; Costanza *et al.* 1992; Waltner-Toews 1993; Gallopín 1994; Giampietro 1994; Nielsen 1994). They represent generic proposals with considerable theoretical and methodological interest that should be tested and possibly redefined in the light of the analysis of concrete situations and case studies. In particular, there is need to develop integrated conceptual frameworks accounting for the specifics of tropical agroecosystems, which differ from the well-studied temperate agroecosystems in a number of important ways.

Drawing primarily on complex systems theories and post-normal science, the intent of the CIAT-University of Guelph Project is to provide a research basis for management actions that improve the health, integrity and sustainability of ecosystems. The framework is being developed in conjunction with a case study in the lower Peruvian Amazon, a site chosen because of its complex web of interconnected issues and pressing nature of the current problems, from deforestation, biodiversity loss, and low soil productivity to urban unemployment, water pollution and institutional instability. It is believed that such an approach will provide us with new insights and a more complete understanding of the complex dynamics of the region, which appears to have resisted understanding and improvement through years of more conventional research methods.

Project Objectives

(i) To develop a conceptual framework for the holistic understanding of agroecosystems as hierarchical systems, using the new ideas derived from Complex Systems theories.

(ii) To apply this framework to concrete tropical agroecosystems in order to assess its applicability and usefulness for guiding research on agroecosystem sustainability.

(iii) To perform comparative analysis of tropical and temperate agroecosystems in terms of systemic properties (on the basis of research on Canadian agroecosystems at the University of Guelph)

(iv) Based on the research findings, to develop teaching materials on complex systems approaches to the study and sustainable care of agroecosystems. These materials will be used in Latin America, Canada and elsewhere.

(v) To train young scientists in the application of concepts and methodologies derived from complex systems theories to the study and evaluation of agroecosystems.

The project began in July 1996 and will continue until mid-1999. It is funded by CIDA's (Canadian International Development Agency) CGIAR-Canada Linkage Fund, a program designed to encourage collaboration among Canadian Universities and CGIAR (Consultative Group on International Agricultural Research) Centres, and CIAT. The Project is based at CIAT in Cali, Colombia.

The Case Study

The tropical agroecosystem which is serving as the test case for developing this conceptual framework is in the Ucayali region of the lower Peruvian Amazon, surrounding the frontier town of Pucallpa. There are a number of reasons why this particular site was chosen. Firstly, CIAT has been working in the Ucayali region since the late 1970s. Although most of the past research has focused on the improvement of "degraded" pastures and cattle production, there are substantial amounts of data and various types of analyses of the area that will be useful when testing the framework. In addition CIAT has strong institutional links with other national and international organizations working in the area.

Secondly, research efforts towards more sustainable use of natural resources in the region have on the whole been relatively unsuccessful and some may argue, inappropriate for tropical ecosystems. In focusing on single issues in isolation from their context, many initiatives have failed to address the overall health of the ecosystem and the key processes, interactions and feedbacks that are critical to well-being of the entire socio-ecological systems. In recognition of the limits of conventional disciplinary and sectoral approaches much research has, in recent years, been broadened to incorporate agroforestry initiatives and the introduction of perennials into the slash and burn cycle. Similarly, research attempts to explain the political and socio-economic context of land use provides much needed insight into the major driving forces shaping the region. While this broadening has occurred for empirically obvious reasons, there has not been a corresponding development of theory to rationalize this work. The intent of this Project is to provide a systemic understanding of multiple interactions across scales in such a way that this broadened research can be better implemented, understood, and provide effective guidance to policy-makers.

Thirdly, the issues which present themselves in Pucallpa are of the nature to necessitate an approach that not only accommodates, but can meaningfully explain the complex interactions, discontinuous and unpredictable system dynamics, and high rates of change in the region. The conditions that dictate in this frontier town, high turnover, transience, heavy resource exploitation in combination with major ecological losses associated with forest clearance and abandonment of land are typical of many vulnerable areas in the Neotropics. Furthermore, the site has international biological significance. Peru contains 23% of the known neotropical plant diversity (9% worldwide) and 44% of the neotropical bird diversity (18% worldwide), concentrated in the Amazon lowlands (IUCN 1996).

A brief look at the recent history of Pucallpa gives a sense of complexity and severity of the problems that have faced and are facing the region. Pucallpa underwent major changes when in the early 1940's it was connected to Lima by road. This prompted the spontaneous colonization of the lower jungle from the highlands. Since that time the region has experienced several economic surges, either in the form of economic opportunities created by policies and/or rapid exploitation of particular resources, for example the rubber and timber boom. In this short-term opportunistic environment issues of long-term sustainable resource use are precluded from development plans. Subsequent to the timber extraction of the 1950's, the national government encouraged cattle ranching and the creation of pastures through input and price subsidies. During this time much land was cleared and "improved" for pasture and cattle production. Later in the 1980's national economic crisis, the terror and chaos surrounding the Shining Path guerilla movement, and the increase in international demand for coca, resulted in a general abandonment of lands and a decline in cattle numbers. There was a substantial shift in labour and resources to coca production. In the 1990's all forms of subsidies were removed. The Banco Agrario, which was the main source of credit for agricultural producers, was liquidated, and Peru was opened to international markets. This created conditions in which economic viability of small land-holders has become increasingly difficult to achieve.

Despite these various waves of economic prosperity and paucity, the general level of well-being of the inhabitants of the region has been declining. Urban migration continues to increase, Pucallpa now represents almost 60% of the total population in the Ucayali region. With this has come urban unemployment, public health issues and the problems associated with rural depopulation and labour scarcity on the farms. The unsustainability of production systems, particularly those associated with pastures has necessitated expansion into surrounding primary forests in order to maintain the same level of productivity. Institutional capacity is low and disordered, policies lack continuity and local governments have little control over national policies that to a large degree shape the region. This lack of social capital undermines the ability to address the critical ecological problems of degraded land, unregulated fresh fishery exploitation, fragmented secondary growth and extensively exploited primary forest.

In summary, Pucallpa provides us with an excellent opportunity to test a framework that addresses competing forces, that attempts to tease out the key interactions and processes and in so doing provide an alternative interpretation of the ongoing problems in the Amazon. This alternative interpretation stems from the application of complex systems theory.

Complex Systems Theory

Despite the recent emergence of complex systems theories, the literature is already replete with competing and sometimes contradictory ideas. It is therefore useful to outline some of the concepts which other researchers have proposed or identified, and which have served as a starting point for our work. The succinct review is intended to be neither comprehensive nor definitive, but to give a sense of the general conceptual terrain we are working in.

Complex systems can be defined as those containing many varied interrelated parts, patterns or elements, thus making complete understanding difficult (Klir 1985). Systems thinking emphasizes connectedness, relationships and context. The essential properties of the parts of a system can only be understood from the organization of the whole, as they arise from the configuration of ordered relationships that is specific to that particular system (Capra 1996). Thus understanding comes from looking at how the parts operate together rather than from teasing them apart. The pattern of organization, represented in the configuration of relationships specific to a particular system, is key to understanding the nature of complex systems. Inherent in complex systems thinking is the recognition of hierarchy (Allen & Star 1982; Allen *et al.* 1984; 1993b). Systems are nested within other systems and therefore are simultaneously comprised of smaller subsystems while being part of a larger system. As one passes from one level to another there are systemic properties that are "emergent", since they only appear at a particular level (Broad 1923; Checkland 1981; Funtowicz & Ravetz 1994; Holland 1995; Capra 1996). Such properties would not be captured by examining only the parts of the system.

Recently, several authors have proposed characterizing complex systems in non-equilibrium terms, and their capability to exhibit discontinuities, irreversibilities, nonlinearities and non-determinancy (Grzybowski & Slocombe 1988). These characterizations have led to the elaboration of four inter-related concepts relevant to describing patterns of structure and behaviour in complex systems: self-organization, attractors, gradients and feedback loops (particularly autocatalysis and autopoiesis).

Central to complex systems theory is self-organization of dissipative structures. Its basic tenet is that open systems that are far from their thermodynamic equilibrium, will at critical points of instability, reorganize themselves at a higher, more ordered, more coherent, and more complex level (Nicolis & Prigogine 1989). This reorganization involves the spontaneous emergence of new structures and forms of behaviour (Capra 1996). Those characterized by a high exchange of energy with their environment, and a continuous dissipation of energy, are called dissipative structures. Dissipative structures continually produce entropy, however the entropy does not accumulate in the system but is part of energy exchange with the environment (Nicolis & Prigogine 1977). In this sense dissipation is no longer considered waste but a source of order. Dissipative structures although stable over a finite range of conditions, can be best represented by autocatalytic positive feedback cycles (Schneider & Kay 1995). As the flow of energy and matter increases, the resulting instabilities and jumps or abrupt changes, are caused by self-amplified fluctuations in the form of these positive feedback loops. This amplification is thus a source of new order and complexity of the system. The points at which these new structures emerge are called bifurcation points, points at which the system may branch off into a completely different state. This necessarily implies the existence of multiple stable states, multiple possibilities, and therefore indeterminacy and unpredictability as the path taken depends on the system's history, and various external conditions that can never be completely predicted. In addition, this process is irreversible, time symmetry is broken (Prigogine & Stengers 1984).

These different stable states can be described as attractors. A stable state (or set of states, such as an orbit) is an attractor and the collection of trajectories determined by the successive states of the system that flow into it is called the basin of attraction. If a lake is the attractor then the basin of attraction is the water drainage flowing into the lake (Kauffman 1995). Attractors are the source of order in a large dynamical system. Since the system follows trajectories that inevitably flow into attractors, attractors will "trap" the system into subregions of its state space. In other words the system sets into a few orderly behaviours, despite the vast range of possibilities

Schneider and Kay (1995) highlight the importance of gradients in their "restated second law".

> *As systems are moved away from equilibrium, they will utilize all avenues available to counter the applied gradients. As the applied gradients increase, so does the system's ability to oppose further movement from the equilibrium.*

Applied in the context of ecosystems, at the most general level, life can be considered a response to the thermodynamic imperative of dissipating gradients (Kay 1984; Schneider 1988). As ecosystems develop or mature they increase their total dissipation, and develop more complex structures with greater diversity and more hierarchical levels to assist in energy degradation (Schneider 1988; Kay & Schneider 1992). Successful species are those that funnel energy into their own production and reproduction and contribute to autocatalytic processes thereby increasing their total dissipation of the ecosystem. This is represented by the development of new dissipative pathways, and an increase in the amount of exergy that they capture and utilize. This would then suggest that disorganizing stresses will tend to cause ecosystems to retreat to configurations with lower energy degradation potential. As has be shown in a number of stressed ecosystems, they often appear to be in an earlier successional stage ecosystems (Shure & Hunt 1981; Nelson-Smith 1977). For example in a stressed marsh ecosystem, it was found in absolute terms all the flows dropped. The stress resulted in the ecosystem shrinking in size, in terms of biomass, its consumption of resources, in material and energy cycling and its ability to degrade and dissipate incoming energy (Ulanowicz 1986).

The development of the above concepts has been derived largely from physico-chemical systems (eg. Benard cells, chemical clocks (Nicolis & Prigogine 1989)), and various computer simulations (eg. binary networks, cellular automata and genetic algorithms (Kauffman 1993; 1995)). Much less has been done on multicellular organisms, ecosystems and social systems. Since many of the pathways and processes in ecosystem are as yet unknown, the description of ecological networks in terms of these concepts is most difficult.

Research Methodology

The application of complex systems theory is but one part of a larger research process that is being developed and implemented in this project. Figure 1 outlines the stages of this research process. Although the research approach draws primarily from complex systems theories, the overall research process is based on ideas and concepts from several approaches including; the ecosystem approach (Kay 1994; Slocombe 1993; Allen *et al.* 1993a); soft-systems methodology (Checkland 1981; 1990); adaptive environmental assessment (Holling 1978; Walters 1986); hierarchy theory (Allen *et al.* 1984; 1993b); post-normal science (Funtowicz & Ravetz 1994) and ecosystem/agroecosystem health (Rapport 1989; Costanza *et al.* 1992; Waltner-Toews & Wall 1996; Waltner-Toews & Nielsen 1995; Gallopín 1995).

A critical characteristics of complex systems that emerges from the above discussion, is that there exists multiple perspectives, multiple truths and therefore no single perception which can provide a comprehensive or adequate view of reality (Funtowicz & Ravetz 1994). Degree of complexity has been equated with the number of non-equivalent descriptions of a systems (Casti 1986). This has important methodological implications. Thus the plurality of different legitimate perspectives and the inability of any one particular view to capture the whole, necessitate a variety of forms of inquiry and inclusion of and dialogue with persons representing different interests (Waltner-Toews & Wall 1996; Funtowicz & Ravetz 1994). This type of inquiry, recently coined post-normal science (Funtowicz & Ravetz 1994), is especially relevant in the context of land use and sustainable development. In such situations the methods of defining critical issues and management goals and the choice of participants involved in the process have an enormous impact on the range and nature of solutions proposed. In this Project considerable effort has been dedicated to the selection of appropriate "local" partners who can aid in incorporating local perspectives and more importantly decision-makers who can act on the information and outcomes of the Project. In Pucallpa CODESU (Consorcio para el Desarrollo Sostenible de Ucayali - Consortium for Sustainable Development in the Ucayali), a non-governmental organization comprised of representatives from all sectors of the community, is one suitable partner through which we hope to gain access to the whole range of interests in the region, from farmers and fishermen to government officials and scientists.

At each stage in the research process we have posed a series of guiding questions. They represent a starting point, the key questions from which other more specific, more applied questions can be derived. For the sake of affecting substantive change in the area of study, it is critical that the entire research process be completed. This is the first draft of the research process. It will be further modified and developed as we progress through the different stages.

The Research Process[1]

Historical Reconstruction

- What has been the overall historical development of the system?
- What have been the key ecological, economic, demographic, and social developments in the system?
- What have been the most significant changes in the structure (components), the pattern of organization (relationships) and the dynamics or processes of the system?
- Which are the critical fast, medium and slow variables within this overall development?
- Is there historical evidence suggesting sudden shifts or bifurcations in the structure or behaviour of the system?

Problem/Issues(s) Analysis

- What are the critical issues?
- What are the management goals and objectives?
- What are the relevant indicators that can measure performance in terms of identified goals?
- What is the range of management actions?
- What are the relevant system variables?

Scaling

- How do we define and delimit the system?
- What are the spatial and temporal boundaries of observation?
- What type of system are we observing?
- What are the key ecological and human processes that define the system?
- What is the nested hierarchy in which the system is situated?
- What are the defining contextual relationships between the system and its subsystems and the larger system in which it is embedded?

Subsystem Models

- What kinds of subsystem models can be developed using conceptual or mathematical modeling

[1] Several of these guiding questions were drawn from an unpublished paper by James Kay titled *Some Notes on: The ecosystem Approach, Ecosystems as Complex Systems and State of the Environment Reporting.* 1994.

techniques?

- How do these models articulate with each other?
- How do those parts of the system which we can model (eg. Hard systems, historical components) articulate with those that we cannot (eg. Soft systems, future-expectation models)?

Re-examination of the System

- What are the key features of complex systems to which we need to pay attention? Eg attractors, gradients - this comes from the basic theory about the nature & behaviour of such systems
- How do we identify those features in a particular case (eg Pucallpa)? ie what are the consequences of such key concepts for research design?

- What are the attractors in the system?
- How do we identify the determinants of those attractors? ie why this attractor and not a different one? This needs to be answered at two levels - theoretically & in the specific case.
- In what direction will the ecosystem tend to develop? What are its propensities?
- What is the behaviour of the ecosystem about the attractor (homeostatic, stable, unstable, chaotic?)
- What sources of information do we need to describe attractors and their determinants?

- Are there bifurcation points?
- What are the potential flips between attractors?
- What triggers the flips?
- How can we monitor them?

- What are the feedback mechanisms that maintain the attractors?
- What are the key feedback cycles?
- Are there particular positive feedbacks that amplify and create "runaway" processes?
- What are the conditions surrounding this?

- What is the core purpose of the human activity system?
- Who are the important social actors/stakeholders in the system, what are their roles and interests? (CATWOE, see Checkland 1981)
- What are the existing power structures ie. the socio-political context?
- Who are the decision-makers?
- What are the rules for identifying and including legitimate stakeholders?

Comparisons

- How does the complex systems model(s) created compare with the research area as originally described in the historical reconstruction?
- Does this re-constructed model bear reasonable resemblance to the reality?
- By using complex systems theory what have we added?
- How is it different to the subsystem models initially developed?

Change

- What are the desirable and feasible changes in the system, in order to reach the identified goals?

Action

- What are the necessary actions and how can they be implemented?

Monitoring

- What are the appropriate indicators to monitor progress and performance of the newly developed plans and strategies?

If one wished to think of these steps in terms of researcher- community interaction, we might suggest that the scaling and historical reconstruction is best done by CIAT researchers alone; problem analysis and subsystem models by CIAT researchers in consultation with stakeholder groups; re-examination using complex systems theory is done mainly by scientists, the comparison of developed models with reality and previous models is done by both scientists and stakeholders, whereas the last few stages, from identifying possible changes, instituting and then monitoring them are mainly stakeholder driven, with facilitation and advice from scientists.

An equally important outcome of this process relates to the ability of the created or modified stakeholder institutions to sustain the process in addressing new problems. Participation in this process should be more than a "one-time" thing. We wish to create institutions in which people can, and do, continue to participate in solving their own problems long after the researchers are gone. This is the ultimate sign of success.

Finally, we emphasize that this process can be used to address many types of problems; it is both iterative and multi-faceted. There is no clear endpoint because agricultural sustainability, in an ever-changing global situation, involves not just environmental conservation and economic viability, but the creation of agricultural institutions and management practices which are responsive, adaptable, and can "learn" as they go. In the process of pursuing this agenda, the CGIAR will itself become a learning institution, whose goal is to create adaptable, learning institutions for agriculture throughout the tropical world.

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MAJOR ISSUES FOR THE PUCALLPA AGROECOSYSTEM

Note: (1) = identified at the first internal workshop (CIAT); (2) = identified in the first Pucallpa workshop; (1+2) = identified in both workshops.

WHOLE SYSTEM:

- Perverse resilience (contagious unsustainability?)(1)
- Road system as organizing principle (1)
- River system as organizing principle (1)

AGRICULTURAL:

- Degraded pastures (1)
- Increased monocropping (1)
- Efficiency of agricultural inputs (1)
- Low cattle inventory (1)
- Low genetic potential (1)
- Lack of agricultural machinery (1)
- Seed supplies (1)
- Utilization of non-traditional crops and agroindustries (e.g. Uña de gato, camu-camu - potential uses of biodiversity) (1)
- Weeds (1)
- Soil fragility and low fertility (2)
- Lack of appropriate agricultural technology (2)
- Irreversible loss of soil/land productivity (3)

FISHERIES

- Depletion and degradation of fishing stocks (1+2)
- Pollution of breeding fish grounds and critical habitats (potential; Inírla, narcotraffick) (1+2)
- Scarcity of information about ornamental and subsistence fishery (2)
- Loss of fish biodiversity due to fishing (2)

ECOLOGICAL:

- Deforestation (1+2)
- Increased fragmentation (1)
- Increased percentage of secondary growth (1)
- Impacts of coca on biodiversity (1)

- Impacts of coca on deforestation (2)
- River pollution (narcotraffick) (1+2)
- Impacts of selective logging (1)
- Lack of inventory or information on biodiversity (1)
- Impacts of activities in floodplain on rivers (1)
- Environmental impact of the exploitation of natural gas (2)

ECONOMIC:

- Transport costs (1)
- Labor and capital scarcity (1)
- Sudden foreign investment and inflow (e.g., DEA) (1)
- No extension services (1)
- Coca - economic impacts (1)
- Unreliable markets, price fluctuations (1+2)
- Extractive and absentee forestry system - little reinvestment in local economy (1)
- Net economic outflow from region/ Net export of resources and benefits (at regional and national level) (1+2)
- Undervalued land prices (because of guerilla, etc.)
- Lack of access to credit (because lack of windows for small loans)

HEALTH:

- Human health problems (maybe) (1)
- Human health deterioration due to environmental degradation (2)
- Water quality (1)
- Urban air pollution (1)
- Lack of sewerage facilities (1)
- Medical uses of biodiversity (1)

SOCIAL AND DEMOGRAPHIC:

- Coca - social impacts (e.g. coca cities)
- Urban unemployment
- Rural to urban migration - social problems (e.g. out migration of youth to Pucallca)
- Urban poverty (no clear problem of rural poverty) (1+2)
- Extractivistic bias (negative attitude towards conservation) (2)
- Widening of the income gap (at the regional, national and international levels) (2)
- Lack of basic services (drinking water, education, health) (2)

INSTITUTIONAL:

- Institutional instability
- Lack of policy continuity
- No land monitoring agency
- Weakness and fragmentation of the environmental regulations (2)
- Lack of environmental content in the educational policies (2)
- Scarcity of policy instruments at the regional level (2)

POLITICAL:

- Power structure (e.g. concentrated power of timber industry) (1)
- Geopolitical context - Amazon seen as important source of development for nation (1)

SCIENCE AND TECHNOLOGY

- Unreliability of the statistics (2)
- Dominance of the productionist approach to research (2)

INDICATORS OF ACCOMPLISHMENT OF GOALS

(Note: discussed only at the Pucallpa workshop)
Note: the indicators are based on the first CIAT workshop and the first Pucallpa workshop; some have been modified. For the present purposes, "agriculture" includes crop cultivation, ranching, and forestry.
"Resource" is a generic term including agricultural land, forest stock, and fish stock.

Goal 1. Enhance Productive Capacity

- *Total agricultural production (volume and value)*
  f(productivity, resource volume)

- *Productivity (total and per factor; in volume and value)*
  f(resource quality, inputs, technology, prices)

- *Land under production*
  f(total available land, land colonization rate, land abandonment/degradation rate)

- *Ratio productive/abandoned land*
  f(land under production, abandoned land)

- *Agricultural diversification*
  f(habitat diversity, producer's objective functions, existence of markets, access to markets)

- *Fish production (volume and value)*
  f(fishery productivity, fishing effort, fish stock)

- *Fishery productivity (volume and value)*
  f(catch per unit effort, total effort, prices)

- *Fish recruitment rate*
  f(fish stock, health of the aquatic ecosystems, fish harvest)

- *Fish species composition*
  f(habitat characteristics, selective harvest)

Goal 2: Increased food production for the Nation

- *Total regional food production*
  f(agricultural productivity, resource volume -land under food crops)

- *Ratio of regional to national food production*
  f(regional food production, national food production)

Goal 3: Protect the environment

- *Greenhouse gases emissions*
  f(area used, land cover, land use technology)

- *Proportion of degraded land*
  f(land quality -or fragility-, land use technology, land under production, total land available)

- *Proportion of land with native vegetation*
  f(land colonization rate, land use technology, initial stock of land with native vegetation, total land area)

- *Deforestation/reforestation ratio*
  f(deforestation rate, reforestation rate)

- *Percentage of protected areas (within specified ecosystems)*
  f(total area, area under production, degraded lands, ecosystem diversity, environmental laws and their enforcement, pressures for production)

- *Mismatch between actual and optimal land use* f(optimal land use, actual land use)

- *Changes in species composition of indicator species*
  f(natural ecological dynamics, land use, water pollution)

- *Indicators of water pollution*
  f(size of human settlements, technology of domestic waste processing, volume of industries, type of industries, industrial technology, water volume/flow)

- *Indicators of aquatic ecosystem health*
  f(ecosystem type, water pollution, fishing pressure)

Goal 4: Sustainable management of biodiversity

- *Proportion of native species with market value*
  f(total number of species, number of species with market value, technology of resource use, volume of resource used)

- *Number of non-traditional species being utilized*
  f(total number of non-traditional species, market- or use-value of non-traditional species, availability of technology, relative profitability of other uses)

- *Habitat loss of wild species*
  f(habitat diversity, habitat sizes, volume of resource use, technology of resource use, pollution)

- *Other indicators of sustainable management (?)*
  f(??)

Goal 5: Increase human welfare

- *Child mortality*
  f(nutrition, education, health, environmental conditions, access to medical services)

- *Average income*
  f(total regional income, total regional population)

- *Income distribution*
  f(employment, tax and reallocation systems, social structure, power structure, ?)

- *Capital accumulation*
  f(capital investments, capital depreciation)

- *Poverty level*
  f(income distribution, total income, social and power structure, education & skills, resource degradation, ?)

- *Unemployment*
  f(labor supply, labor demand)

- *Morbidity (diarrheal, respiratory)*
  f(same as for child mortality)

- *Satisfaction (suicide rates)*
  f(living conditions, cultural and psychological factors)

- *Crime*
  f(regulatory and enforcement systems, social structure, poverty level, community health)

- *Social support networks -community health*
  f(social structure, culture, enabling systems, power distribution)

Goal 6: Empowerment of local institutions

- *Local market versus central government determination of prices of agricultural produce (ratio)*
  f(strength of local markets, national political system, governmental application of instruments, ?)

- *Dependency ratio: ratio of regional economic product to the total value of imports and exports*
  f(regional production capacity, extra regional markets, national and regional policies, ?)

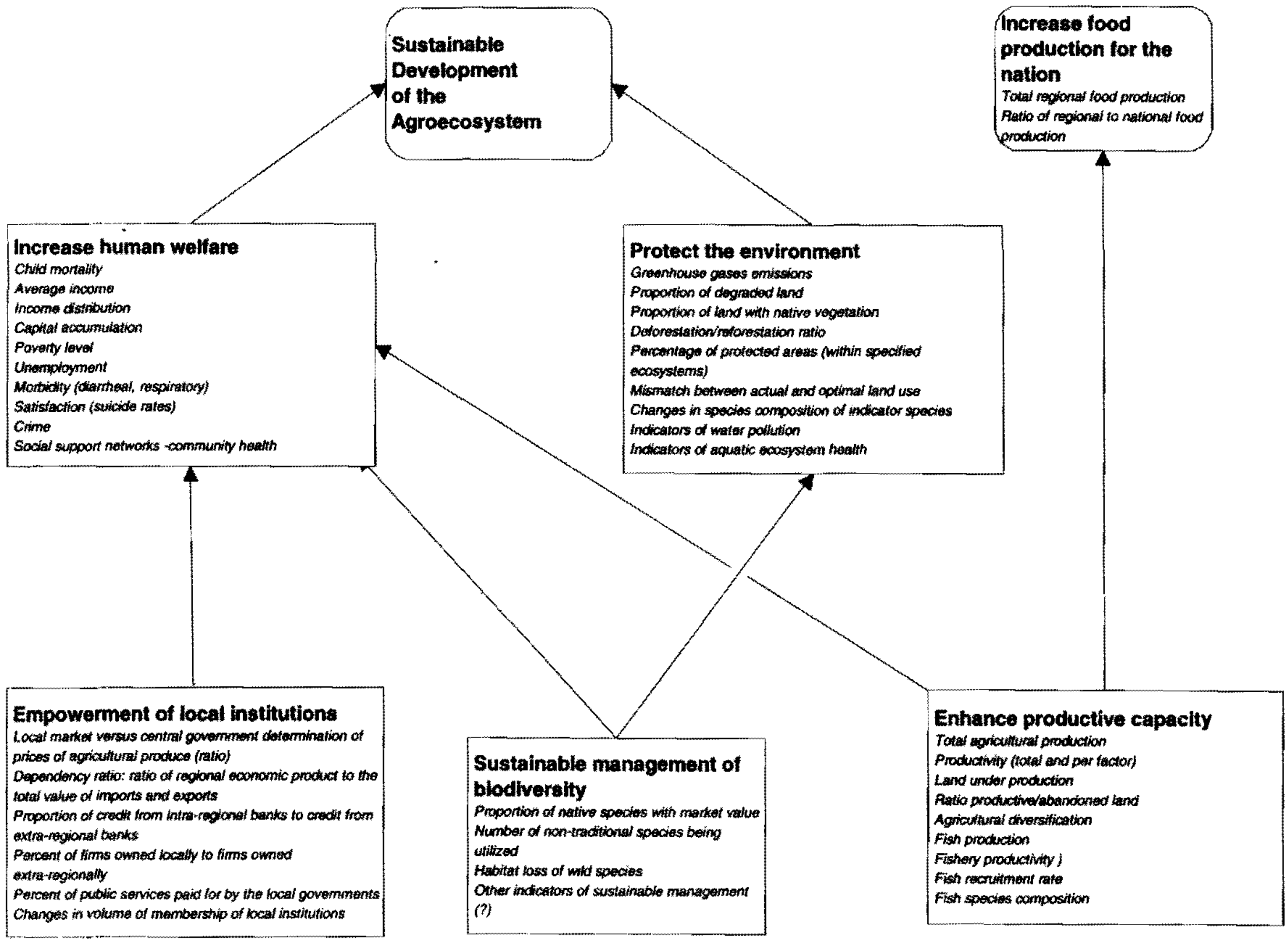
- *Proportion of credit from intra-regional banks to credit from extra-regional banks*
  f(banking regulations, volume and diversity of intra-regional banks, national and regional policies)

- *Percent of firms owned locally to firms owned extra-regionally*
  f(power structure, regulations, regional productive capacity, time since establishment of the firms, ?)

- *Percent of public services paid for by the local governments*
  f(national and regional/local policies, regional productive capacity)

- *Changes in volume of membership of local institutions*
  f(number of local institutions, culture, social structure, time since establishment of local institutions, perception of usefulness of local institutions, perception of usefulness of extra-regional institutions)

GOALS AND THEIR INDICATORS



Brief Overview of Past Activities of the CIAT-University of Guelph Project
May 1997

1. **Bibliographic searches** of both peer-reviewed and grey literature were completed on
   - (i) Complex systems
   - (ii) Definitions of Sustainable agriculture
   - (iii) Agroecosystem health
   - (iv) Previous research projects and activities in Pucallpa, Peru

2. **Databases** have been created based on the above searches and reviews have been initiated.

3. **Draft project working papers** have been prepared on
   - (i) A review of agroecosystem health, drawing in particular on the work of the University of Guelph's Agroecosystem Health Project.
   - (ii) A review of the relevant systems literature
   - (iii) A review of the history and dynamics of the Pucallpa region

4. *Development and Application of an Integrated Conceptual Framework to Tropical Agroecosystems Based on Complex Systems Theories: CIAT-University of Guelph Project.* Article describing the Project and its rationale for Ecosystem Health Journal.

5. The **M programming language** has been acquired and a preliminary simulation model of land use dynamics at Pucallpa has been created

6. Compilation of **quantitative multi-sectoral** data suitable for GIS has been initiated

7. The case study site in Pucallpa has been visited by the research associates and leaders of current projects related to Pucallpa were consulted in both Pucallpa and Lima.

8. A **diagram of the research process** required to achieve a complex systems model, based on the best available scientific and local knowledge, and to initiate actions to evaluate and improve such a complex system, has been created. This process diagram is expected to guide much of what will follow and to result in a wide variety of outcomes.

9. **The first internal workshop of the Project** was held at CIAT on March 3, 1997, followed by a series of consultations to identify key issues/ problems in the case study site and to begin process outlined in the diagram.

10. On May 6 1997 CIAT scientists conducted a workshop with CODESU in order to ascertain the perspective of local community members and to better understand what thet see as the key issues/problems in the region.

11. CIAT scientists participated in a workshop in Iquitos on Strategic Planning for the Peruvian Amazon. All the regional departments of the Ministry of Agriculture were present. We worked with the Director of the Ministry of Agriculture and her colleagues from the Ucayali Region.

Summary Table of the Main Institutions, their Missions and Activities in Ucayali.

Institution	Mission	Activities
PUBLIC		
Insitituto Nacional de Investigación Agraria (INIA)	Increase the productivity of the principal crops and animals through research	Production of improved varieties Production of female sheep, guinea pigs and ducks Introduction of new forage species and recuperation of degraded pastures Evaluation of the production of sheep Research into different agroforestry models
Insitituto de Investigaciones de la Amazonia Peruana (IIAP)	Increase the development of the occupied parts of the Amazon Develop alternatives land use	Aquaculture Inventory and reproduction of forest species Evaluation of species for pharmaceutical, food and agroindustrial uses Technologies for the industrialization of wood Industrialization of regional food Ecological evaluation of natural resources Cartography for environmental planning
Comite de Reforestacion	Reforestation of open areas	Plantations Communal reforestation Forestry Management

Fondo de Compensación para el Desarrollo Social (FONCODES)	Reduce extreme poverty Provide infrastructure, health and education services	Supply portable water Rehabilitation of sanitation centres Rehabilitation of schools Road infrastructure Rural electrification Projects financing agricultural and fishery production
Instituto Veterinario de Investigaciones Tropicales y de Altura (IVITA)	Through research, increase in the production and the productive capacity of animals considered a regional and national priority	Research in agrosylvian systems Diagnosis and control of rabies and *brucelosis bovina* Artificial reproduction of fish Agronomic evaluation of medicinal species Management of a regional herbary
Ministerio de Agricultura	Strategic planning for agriculture Administration and control of non-renewable resources in the region	Promotion of agricultural activities Organize the agricultural producers Extension Agricultural research Training Reforestation Address land ownership and other legal issues related to resource use
Ministerio de Pesqueria	Administration and control of the fishery resources	Fishery research Registration of fish catches in the ports
Universidad Nacional de Ucayali (UNU)	Train professional to contribute to regional and national development Conduct research that contributes to development	Improve teaching Agricultural research in medicinal plants, crops, animals, plant health and non-conventional energy

PRIVADAS Consorcio para el Desarrollo Sostenible de Ucayali (CODESU)	Coordinate institutional activities directed at sustainable development in the region	Analysis of planning policies of the region Evaluation of leguminous forages and milk production systems that can rejuvenate degraded pastures Formulation of inter-institutional project proposals for the development of sustainable land uses. Formulation of national proposals for the stabilization of migratory agriculture and sustainable management of the forests Development of production, processing and commercialization of palmito de pijuayo, camu-camu and una de gato.
Centro Internacional para la Investigación en Agroforestería (ICRAF)	Conduct, in collaboration with national institutions, research on the development of agroforestry technologies for sustainable land use Promote activities of training, education and communication of agroforestry	Analysis of land use systems Contingent valuation of natural resources Policy analysis Domestication of agroforestry species Study on the interaction of trees, crops and the environment Evaluation of agroforestry systems Research on food systems for dual-purpose cattle
Asociación Inter-etnica de Desarrollo de la Selva Peruana (AIDESEP)	Promotion of the self-determinacy, identification, organization, rights defense of indigenous territories Support the development of bilingual and intercultural education Promote the re-evaluation of medicinal plants	Land registration of native communities and communal reserves Indigenous health in Atalaya, Gran Pajonal y Tahuanía

Sources: Riesco, A & Arroyo, M. 1997. Perfil socio-economico de la región de Ucayali; Iquitos Workshop, 1997.

Summary of Current and Future CIAT Activities in Pucallpa
April 1997

Project	Goals & Objectives	Assumptions	Scale	Methodology	Outputs	Target Groups
Tropileche	* Improve production and utilization of feed resources * Improve feed quality and supply * Develop feeding strategies in crop-livestock systems * Improve soil productivity and mitigate soil and pasture degradation	* Milk and meat are basic part Latin American diet * Dual-purpose cattle provide the most efficient means of increasing production and income * Small farmers dominate dual purpose cattle production	* Plot * Farming system * Community/ Landscape	* Experiments: feeding and grazing trials * Ruminant optimization modelling * Participatory on-farm research * Land use and economic characterization * Environmental impact assessment	* Increased efficiency in the use of forage resources for milk and beef production * Known potential of different forage resources for increasing milk and beef production * Information on the demand for, acceptability and environmental impact of new forage systems	* Small landholders

Rural Agroenterprise Development (re Pucallpa only)	* Generate methods and tools to facilitate design of successful rural agroenterprise development projects	* Welfare of rural population will improve through linking smallholders with growth markets	* Community/ Landscape	* Participatory methods	* Participatory methods for selecting agricultural products with market potential (fresh and processed) * Guidelines and local policy options for the promotion of rural agroindustry within context of microregional strategy for sustainable agricultural development	* Small landholders
Project	**Goals and Objectives**	**Basic Assumptions**	**Scale**	**Methodology**	**Outputs**	Target Groups

CIDA Project	* To develop a conceptual framework for the holistic understanding of agroecosystems (AES) as hierarchical systems, using the new ideas derived from Complex Systems theories. * To apply this framework to concrete tropical AES in order to assess its applicability and usefulness for guiding research on agroecosystem sustainability. * To perform comparative analysis of tropical and temperate AES in terms of systemic properties (AESH Project, U of Guelph) * To develop teaching materials on complex systems approaches to the study and sustainable care of AES. * To train young scientists in the application of concepts and methodologies derived from complex systems theories to the study and evaluation of AES.	* Sectoral and single disciplinary approaches have failed to capture key interactions among social, economic and ecological variables * Past research efforts toward sustainable use of natural resources have for a number of reasons been largely unsuccessful in the region * Use of complex systems theory will provide new insights into system dynamics	* Landscape (however with focus on cross-scale interactions)	* Simulation modelling * Participatory research (CODESU) * Application of conceptual framework * Remote Sensing: time series	* Simulation model * Databases: Pucallpa and complex systems * Conceptual Framework * Methodology for research on agricultural sustainability * Indicators reflecting complex systems theories * Training materials in English and Spanish * Reassessment of research priorities in the region	* Policy-makers * Local decision-makers * Agricultural researchers

Project	Goals and Objectives	Basic Assumptions	Scale	Methodology	Outputs	Target Groups
Ethnobotany and Indigenous Knowledge	* To understand indigenous plant knowledge, taxonomy and use	* Agroforestry research is best built on farmers' practices and knowledge	* Landscape	* Ethnographic eliciting * Key informant interviews	* Data base	* Global good * Local communities
Land use Characterization	* To characterize land use dynamics	* Land use change is key to understanding other dynamics within the system	* Landscape	* Surveys * Interviews * Remote sensing analysis	* Characterization of land use dynamics	* Global * Local
Plant Community Diversity	* To understand plant biodiversity and community change as a fucntion of land use change	* Landuse affects biodiversity * Biodiversity has important ecological significance in the region	* Amazon	* Traditional botanical surveys and inventories	* Understanding of plant dynamics	* Global Good
Ecology of Successional Ecosystems	* To identify natural mechanisms by which productivity is restored	* Fallow periods are essential in low-input agriculture/pasture	* Landscape/ ecosystem	* Correlation of structural functional ecosystem properties along chronosequence * Effects of experimental manipulations	* Information on natural limits to exploitation * Options for more intensive land use	* Researchers

Appendix Two

OVERVIEW AND SYNTHESIS OF THE PUCALLPA-UCAYALI REGION, E PERU -CASE STUDY- May, 1997

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David Waltner-Toews

INTRODUCTION

This overview and synthesis of the Pucallpa-Ucayali region is provided within the context of the CIDA-funded project "Development and Application of an Integrated Conceptual Framework for Tropical Agroecosystem Research Based on Complex Systems Theories". The project is jointly executed by CIAT and the University of Guelph (Canada).

The project will focus its application on the Amazon lowlands, an extended region that faces the conflict between high natural richness and increasing conversion of wild lands to monocrop agriculture and cattle ranching. A case-study site has been chosen in the Pucallpa-Ucayali region of Eastern Peru (Andean or Western Amazonia). CIAT has worked in Pucallpa for more than two decades.

The Data Set

This document is based upon three main sources of information: (1) literature review, mostly of CIAT and Peruvian sources; (2) repeated consultation and confrontation of views among CIAT personnel working in Pucallpa; and (3) extensive consultation with Peruvian experts and non-CIAT international R&D scientists working in Pucallpa.

We must warn the reader that the quality and scope of our data set is heterogeneous. CIAT's activities in Pucallpa (and those of its Peruvian partner organizations) have focused in the development of technologies for the improvement and maintenance of extensive cattle ranching based upon forages adapted to the region's poor soils. Thus, little information not specifically related to pasture trials is available at CIAT. Also, CIAT's information concentrates in the 1980s, with some reference to the 1970s. Its historical and present value is, thus, limited. Very recently, Drs. Sam Fujisaka and Erik Veneklaas (CIAT), and Dr. Joyotee Smith (CIFOR, formerly CIAT) have started intensive work in Pucallpa, on farm-level land use and its ecological-economic determinants. Their initial data are still unpublished.

Information produced in Peru is scattered throughout several hierarchy layers and across a number of offices in several governmental and non-governmental organizations, as well as in the hands of individuals. This information is historically incomplete, of uncertain reliability, and heterogeneously aggregated. Frequently, different governmental offices will provide conflicting figures for the same subject. Perhaps worse, past official statistics (even from the 1980s) have often disappeared from office, due to organizational changes and other accidents. When information exists, a common problem is that absolute ranges and point-data are lost within badly documented class-categories and divisions that tend to change from time to time. The technical quality of the data is severely heterogeneous, worsening as we move into the past. Finally, there is always the ghost of short-term political interests distorting the data.

Thus, it should not come as a surprise that there is a severe scarcity of scholarly or technical works that quantitatively analyze and compare the study region in terms of patterns, trends or processes. This situation seems to be improving during the last few years, stimulated by new resources and attitudes. However, thorough economic, ecological or social analyses are still missing even for the most important activities of Ucayali. In this context, it is too easy to end up relying on data-less or non-corroborated hypotheses, more or less informed/prejudiced opinions, and plain speculation. We have made a sincere effort to avoid all these traps, and feel reasonably confident of the information here provided.

Scope of the Document

In practice, we are interested in the period between 1940 and the present; the period when colonization turned into a significant driving force in the study region. It is between 1950 and 1970 that Pucallpa received the human flows that shaped its present landscape. Since 1960, Peru as a nation experienced several structural changes that directly affect our understanding of the country and the study region. Above all, in 1968 a leftist military coup led to a radical overturn of the structure of land ownership. Suddenly, Peruvian land ownership turned from highly concentrated among a few families into the less concentrated land of the Americas. The military dictated a state monopoly on all the large industries (oil, mines, energy, communications) and established a state monopsony on agriculture. Since 1980, at the end of the military period, Peru suffered deep economic crisis, acute political violence, and the cocaine boom. Since 1990, the authoritarian regime of twice-elected president Alberto Fujimori controlled macroeconomy and terrorist guerrillas, and started a still ongoing process of economic liberalization, including extensive re-privatization of industries and land. The effects of these last developments are unfolding as we write.

Looking at Ucayali from a cross-scale perspective, several significant scales may be identified. Sensible scales below and beyond the regional level include the farm (farmer's rationality and decision making); the subregion (e.g., Pucallpa city, road to Lima); an inter-regional level, probably affecting access to land, labor, product diversification, and the dynamics of population migration; and the national level and above. This introductory document will focus on the region. The regional level facilitates inter-disciplinary discussion of complex realities (Hengsdijk & Kruseman 1993). Our focus on the region is also an effect of data availability.

Finally, although in this document we will focus in the recent past (1980s and early 1990s), we want to stress the importance of the much wider historical context that embraces the region. Peru is a territory occupied and modified by humans during more than 10,000 years. Although it will not be treated in this text, we can track some key organizational characteristics of Peru and the study region back to Pre-Hispanic times.

DESCRIPTION OF THE STUDY SITE

Precautionary Note

Perú shares with Colombia, Ecuador and Bolivia a triple geographical identity: Pacific, Andean and Amazonian. The Amazonian regions in these three countries are quite different from one another, both ecologically and socioeconomically. Moreover, Andean or Western Amazonia, taken as a whole, is significantly different than Brazilian or Eastern Amazonia, both in ecological and socioeconomic terms. Thus, before Amazon-level generalizations can be made, upon the base of one site's information, researchers should carefully confront their knowledge with other sites in the region.

Pucallpa-Ucayali

Ucayali is an administrative region and a department in Peru. The Ucayali region, located in the central Amazonian lowlands, extends across 110,831 km^2 and is populated by 366,912 people (1996; INEI 1997). The large Ucayali river, born in the Andes, flows throughout, from south to north, along 1,600 Km. The Ucayali river joins the Marañón river to form the Amazon (Map 1).

Pucallpa, located on the left margin of the Ucayali river, at 154 m.a.s.l., is the region's capital city. Pucallpa is directly connected to the nation's capital, Lima, by plane and by 842 Km of road (Map 2). Pucallpa is the most important river port of Peru's central Amazonia.

Human population in Ucayali concentrates in Pucallpa city and along the road to Lima. Geographically, this area corresponds to the Aguaytía river's basin, which extends over 16,995 km^2, and holds 322,000 people (IIAP-CRP 1996; Map 3). Traditionally, agricultural research has focussed on a sample of this area, which covers no more than 1,000 km^2 (Map 3). The rest of Ucayali is very sparsely populated, down to 0.2 people/km^2 in the remote province of Purús.

Average temperature in Pucallpa is 26-28 °C. Rainfall (~2000 mm/year) is slightly biseasonal, with March and October peaks, and clear skies between June and August (Figure 1). Ucayali's natural landscape is dominated by large meandering rivers, lowland and piedmont rainforests, and their associated land forms (floodplains, sand beaches, oxbow lakes, terraces, uplands). While the floodplains are seasonally covered by rich sediments from the Andes (entisols), the extensive forest-covered uplands bear ancient, acid, and infertile soils (ultisols). Although a thorough assessment does not exist, Ucayali is internationally considered a region of very high biological diversity and highest conservation priority, based upon ecosystem diversity, species richness, and endemism (FANPE 1996).

Historical Background

More than 60% of Peru's territory is covered by rainforests. Arable land is very scarce. This situation, combined with the wrong perception of Amazonia as an empty and highly fertile region, has fed ideologies and policies of Amazon conquest. Colonization of the Peruvian Amazon has been repeatedly stimulated by the construction of penetration roads and by subsidies. Modern Ucayali is one result of these policies. A brief history of the Pucallpa-Ucayali region is offered in Box 1.

Ucayali started to grow rapidly in the 1940s, when a road connecting Pucallpa (Ucayali's capital) to Lima (Peru's capital) was built. Spontaneous colonization from the Andes followed. Pucallpa turned by the 1950s into the timber capital of Peru. The opening of logging roads stimulated further encroachment of spontaneous colonists.

Since the mid 1970s, Pucallpa has been an active study site for CIAT and its partner Peruvian R&D institutions (chiefly IVITA and INIA). Research came to a halt at the end of the 1980s, due to political violence, but it has enthusiastically resumed in the last years. Recently, ICRAF and CIFOR initiated new research in the area.

DEMOGRAPHY

Figure 2 shows the demographic dynamics of Pucallpa-Ucayali since the 1940s. The region's average growth rate (5.3%) is well above Peru's (2%). Urban population is 65.1% of the total, and it concentrates in Pucallpa city (88% of the urban population). This follows a global and national trend (Perú is 70% urban, concentrated in Lima city). Ucayali contributes only 1.5% to the total population of Perú (INEI 1994).

According to INEI (1995), Ucayali, with 77.3% of its population in poverty, occupies the twelfth place among Peru's departments; but is well above the national average (56.8%). Moreover, 43.9% of Ucayali's inhabitants live in extreme poverty (national average is 28.4%). Fifty four percent of Ucayali's poor are urban; however, poverty among the rural population is 94%. In Pucallpa city, 59.7% of the population are poor. Mortality before the first year of age among the poor is above 73 per 1000 in Ucayali (against 66.5 per 1000 in Perú) and about 50 per 1000 among the non-poor (against 36.7 per 1000 in Perú). Still, infant mortality in Ucayali ranks it ninth among other departments. In summary, Ucayali is among the poor but is far from being the poorest region in Perú, both in relative and absolute terms.

ECONOMY

In spite of the investment in roads, the repeated subsidies, and a few economic booms, Ucayali's contribution to Peru's GNP has consistently been low (near 0.9%). Figure 3 shows Ucayali's GDP over a 14-year period. During the 1980s and 1990s, the primary (extraction) and secondary (transformation) sector contributed more than 60% of the regional GDP. We will concentrate our analysis on these sectors, since they are directly related to natural resource use in Ucayali. As shown in Figure 4, the main subsector in the primary GDP is the agro-sylvan (agricultural and forest products). Much less important in value is fishery, the only other primary subsector related to direct exploitation of renewable resources.

The most important economic activity in Ucayali is the exploitation of timber from natural forests. About 40% of Ucayali's human population depend directly or indirectly on this activity (CDC-Perú 1991). This is a structural feature of Ucayali's economy (INFOR 1986). Figure 5 offers an instance of such feature. However important, the timber activity suffers from severe structural limitations. In spite of the enormous diversity of the forest (estimated in ~2,500 tree species), only about 250 are used, and intensive commercial logging is limited to about twenty species of high market value or with a well-established demand. Moreover, while the estimated commercial volume of the forests around Pucallpa is about 100 m^3/Ha, only 5-7 m^3/Ha are commercially extracted (Barrantes & Trivelli 1996). In spite of its great selectivity, timber extraction happens with very low quality standards, wasting the resource and causing extensive damage to the forest. Reforestation or silvicultural practices are almost never applied, leaving behind impoverished forests in both their genetic and economic value. On the other hand, the industry shows great disarticulation between extractors (mostly individual peasants who happen to own a chain saw), industrials (sawmill owners, the most important from outside the region), and specialized middlemen and merchants (many also from outside). Up to 64% of the timber destined to the internal market, and up to 96% of export timber are absorbed by commercial enterprises based outside the region, so that Ucayali experiences a severe capital drain as its natural resource base degrades.

Figure 4 suggests that fisheries play an insignificant role in Ucayali's economy. While this may be true in terms of money, in volume, freshwater fisheries supply the most important source of animal protein in the region (Figure 6). Being extracted from lakes and rivers with low effort and small investment, fish are a cheap and excellent food. This is a clear example of the largely unaccounted subsidy from nature that supports Ucayali's economy and population.

R&D and Technology for Renewable Resource Use

Boxes 2 and 3 provide basic information on the main agricultural and natural resource R&D institutions working in Ucayali, and on the available technology for renewable resource management in Ucayali. The value of current research and technology for the sustainable development of the Amazon is a contentious matter in Perú and abroad. While some experts claim that enough is known and has been developed for the integrated sustainable management of Western Amazonia (F. Razzetto, pers. comm., November 1996; A. Brack, pers. comm., May 1997); other experts reject that notion (J. Dancé, pers. comm., and meeting with CODESU directors, May 1997), and in practice prefer to rely on more traditional approaches to development.

Substantial to this debate are conflicting views on technology transfer and adoption. In Ucayali, adoption of new technology has been meager over the years. When adoption has been high, as with the adoption of *Brachiaria* improved grass, factors quite different than active transfer may have been on play (see below). Thus, advocates of the "enough technology" thesis also blame the agricultural R&D institutions of inadequate priority setting for the development of improved technology, and of inadequate transfer efforts. Central to the discussion are the rationality and priorities of the local stakeholders. Without taking party on the main issue, it must be accepted that R&D in the region has traditionally suffered of top-down and technocratic biases that could have affected the adequacy of technology or its odds of adoption. Following global trends, this traditional approach to R&D could be changing recently, although signs are still weak and indecisive.

LAND USE

Here we offer a summary and simplified version of the land use dynamics that supports the region's economy. Figure 7 offers a more complete and complex description, that reflects our current consensus. Figure 8 ranks the land transformation pathways by their perceived frequency of occurrence.

Land use transformations in Ucayali start with selective logging. Under government permission, extractors large and medium exploit natural forests for a handful of timber species of high market value (mahogany, tropical cedar, "lupuna", and a few other). Logs are transported to sawmills in Pucallpa mostly by river. The products (lumber, flooring tiles, and plywood) are later taken to Lima by road. Colonists also log the natural forests, in a slightly less selective manner, as they tend to exploit smaller individuals of the finest species and a few more species of lower market value ("copaiba", "bolaina blanca"). Historically, logging roads have favored spontaneous invasions of timber concessions by colonists, providing an excuse to the relatively meager production of even the largest logging companies.

In the land abandoned by the timber companies or in their own already logged lands, small to medium colonist farmers slash-&-burn the forest (1-2 ha/yr) and plant annual crops. As labor and capital constraints preclude soil conservation practices, soil fertility, temporarily enhanced by the forest ashes, falls in 1-2 years below annual crop productivity. Some fallow-crop rotation may happen, but fallow is usually short-term, and eventually soil fertility falls well below annual crop productivity. Then, improved pastures are planted or allowed to encroach from neighboring lands or native pastures are encouraged and maintained by repeated burning and grazing. Pastures are largely established to protect land claims and increase land market value (most people have pastures without cattle). Cattle have value mostly as on-hoof savings, and provide some social status.

New cropland is obtained by slash-&-burn of primary or secondary forest. As soil fertility keeps decreasing, a number of fallow-pasture schemes are usually essayed by the farmers, but pastures are eventually rendered largely unproductive. Through time, land accumulates into several types of low-investment, low-productivity pastures and long-term secondary growth. In spite of its impact on the land, cattle production is very low. As already shown (Figure 6) main animal protein in the region is freshwater fish, consumed ~10 times more than beef. The system reproduces and expands slowly by the selective logging, occupation and clear cutting of more natural forest. However, deforestation in the region has only been significant in the area of influence of roads, where human population and market flows concentrate.

Land Use Categories

Following Figures 7 and 8, the main categories of land use in Ucayali are:

Natural forest: Original forests of the lowlands and uplands, including riverside successional forests. They have been extensively settled by indigenous peoples over thousands of years, subject to low-intensity **hunting, gathering,** and **shifting agriculture**.

Degraded forest: Primary forests defaunated and wood-impoverished, after extensive hunting and selective logging. High-intensity **hunting** and uncontrolled **selective logging** without silvicultural management erode the community structure and the genetic pools of the forest, threatening their long-term productivity and renewal.

Villages and cities: The only main city is Pucallpa itself, at the East end of the main road to Lima. with ~200,000 inhabitants. Smaller settlements occur along the main and secondary roads, and along the rivers.

Annual crops: Main crops are plantains, manioc, rice, and grain corn. These are **planted** in monoculture, following **slash-and-burn.** No significant fertilizer or pesticides are applied. Management of crops is limited by labor scarcity. The main fertilizer are the ashes. Plantains and manioc are the region's main staple food. Rice and corn are cash crops which establishment was government-subsidized.

Permanent crops: Planted perennials, both native and exogenous. Main economic perennials are citrics, oil palm, and coca.

Improved pastures: Pastures are **planted** right after **slash-and-burn** or when **soil fertility declines** below **annual crop** productivity. Main improved forage is *Brachiaria* grass, almost ubiquitous in the Pucallpa area. Pastures do not receive significant management.

__**Native-Dominated pastures:**__ As **soil fertility declines** in planted pastures, **invasion of native** grasses may occur[1], rendering a savanna-like terrain of low productivity. Under repeated fire and permanent grazing, this stage may be permanent. In their absence, provided the presence of **forest seed banks**, and depending upon the relative action of **seed predators** and **seed dispersers** these pastures may eventually become secondary growth. A possible variation to this pattern is the invasion of *Brachiaria* grass. The aggressive root system of **Brachiaria** seems to allow it to displace native grasses, and could explain the apparent rarity of native pastures in the Pucallpa area (ERL, pers. obs., and D. Bandy, pers. comm, May 1997).

Secondary growth: Successional stages in abandoned or fallowed clearings, dominated by trees that eventually form a closed canopy. Biodiversity is typically much less than in natural forest.

Figure 9 shows the major outputs from land use in the region, in terms of products (tangible outputs) and services.

SOCIAL ACTORS

In order to adequately understand this section, the reader should keep in mind that diversity must be expected within each of the social groups here identified. Diversity within groups arises from different origin of peoples, different times of arrival, different levels of poverty, gender differences, and different natural base in their sites of settlement.

There are two versions of a central government: national and regional. Regions and regional governments were created in the late 1980s as a means to better distribute economic and political power in severely centralized Perú. However, Fujimori's government has taken back most of the original power and autonomy of regional governments. All important decisions are still taken in Lima. Sectorial offices respond to the central government, although they receive funds through the regional government. Political and technical sectorial personnel are unstable, the average service period of a regional or local decision maker being less than one year (with a few remarkable exceptions). Regional and local policies are concomitantly short-termed. Municipality-level governments (local) are of a different (more democratic) nature, and often play a significant role at the grassroots; although they are chronically under-budgeted and understaffed.

Important private interest groups and stakeholders include Indians, farmers (mostly small crop/livestock producers, loggers, and coca growers[2]), artisanal fishermen, merchants, and timber

---

[1] "Torourco" association, dominated by *Axonopus compresssus* and *Paspalum conjugatum*.

[2] In practice, these identities may overlap.

companies (extractive, industrial, and commercial). Grassroots and small producer organization is very weak in Ucayali. Although their impact has never been assessed, drug dealers must be taken into account, for their acute potential effect on land use, demographic changes (migration), and markets.

Urban groups in Ucayali are the unemployed, the people employed in services, the bureaucrats, and some industrialists. Researchers and technocrats from NGOs, national, and international research institutions play lower-profile roles in Ucayali's socioeconomic dynamics; but their impact in the long term may be significant. A list of the main social actors follows:

- Government
  - National
  - Regional
  - Municipal (local)

- Economic groups
  - Drug dealers
  - Large timber extractors, industrials, middlemen, and merchants
  - Agricultural producers / small timber extractors / coca growers
  - Merchants
  - Artisanal fishermen
  - Bureaucrats
  - Urban unemployed

- Ethnic groups
  - Amazonian Indians

- Other
  - Broad-based alliances and NGOs
  - Research institutions (national and international)

SYNTHESIS

Boxes 4 and 5 summarize the main socioeconomic and ecological features of the study region. As the 1990s reach an end, agricultural/renewable resource R&D projects in Ucayali re-flourish both among international and national institutions. Still, a great deal of uncertainty surrounds the Pucallpa-Ucayali region, as the economic and ecological values of the land decline, and traditional exogenous and endogenous constraints keep in action.

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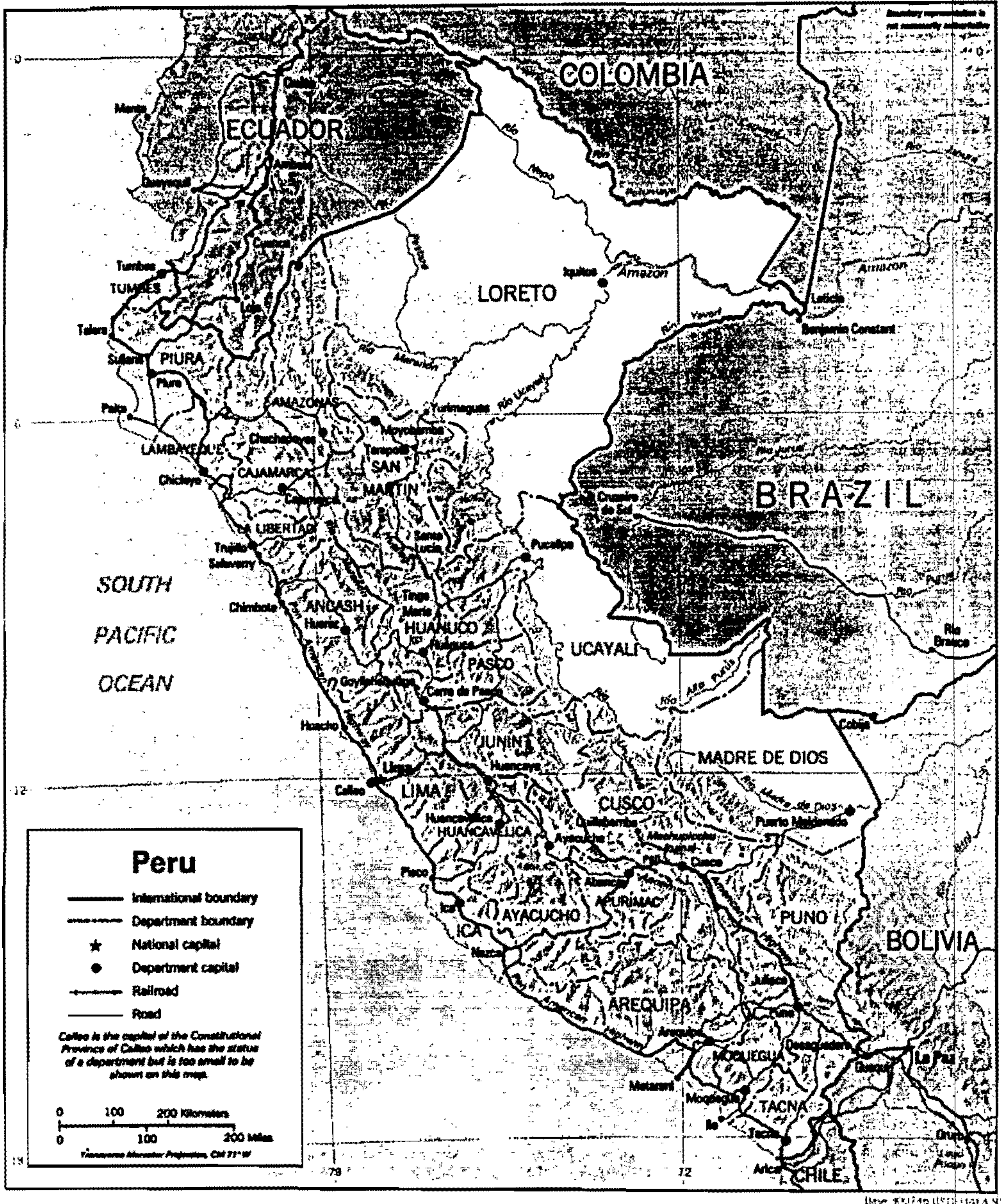
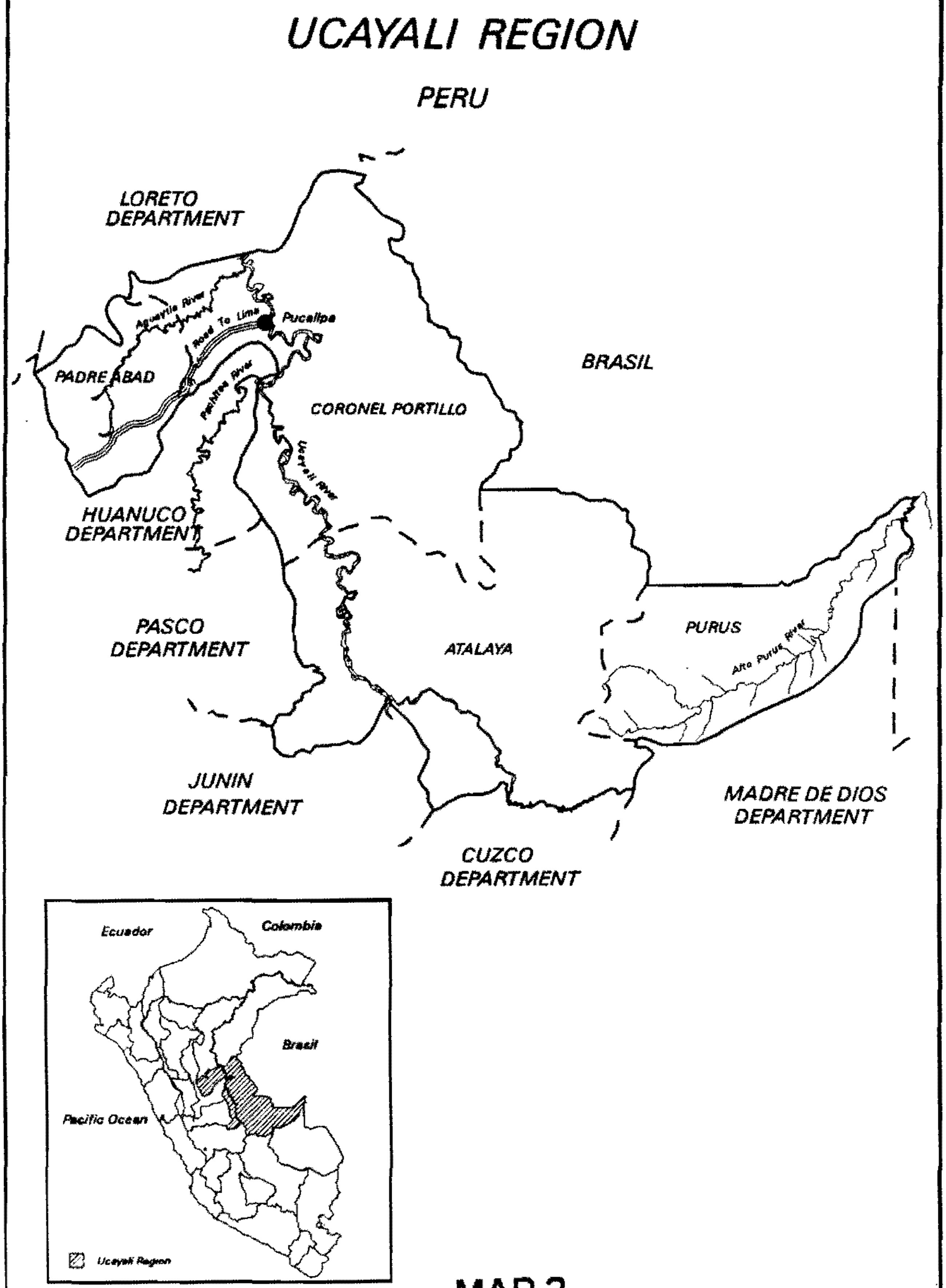
ACKNOWLEDGMENTS

To Víctor M. Soto and Silvia E. Castaño, at CIAT's GIS lab, for drawing maps 2 and 3.

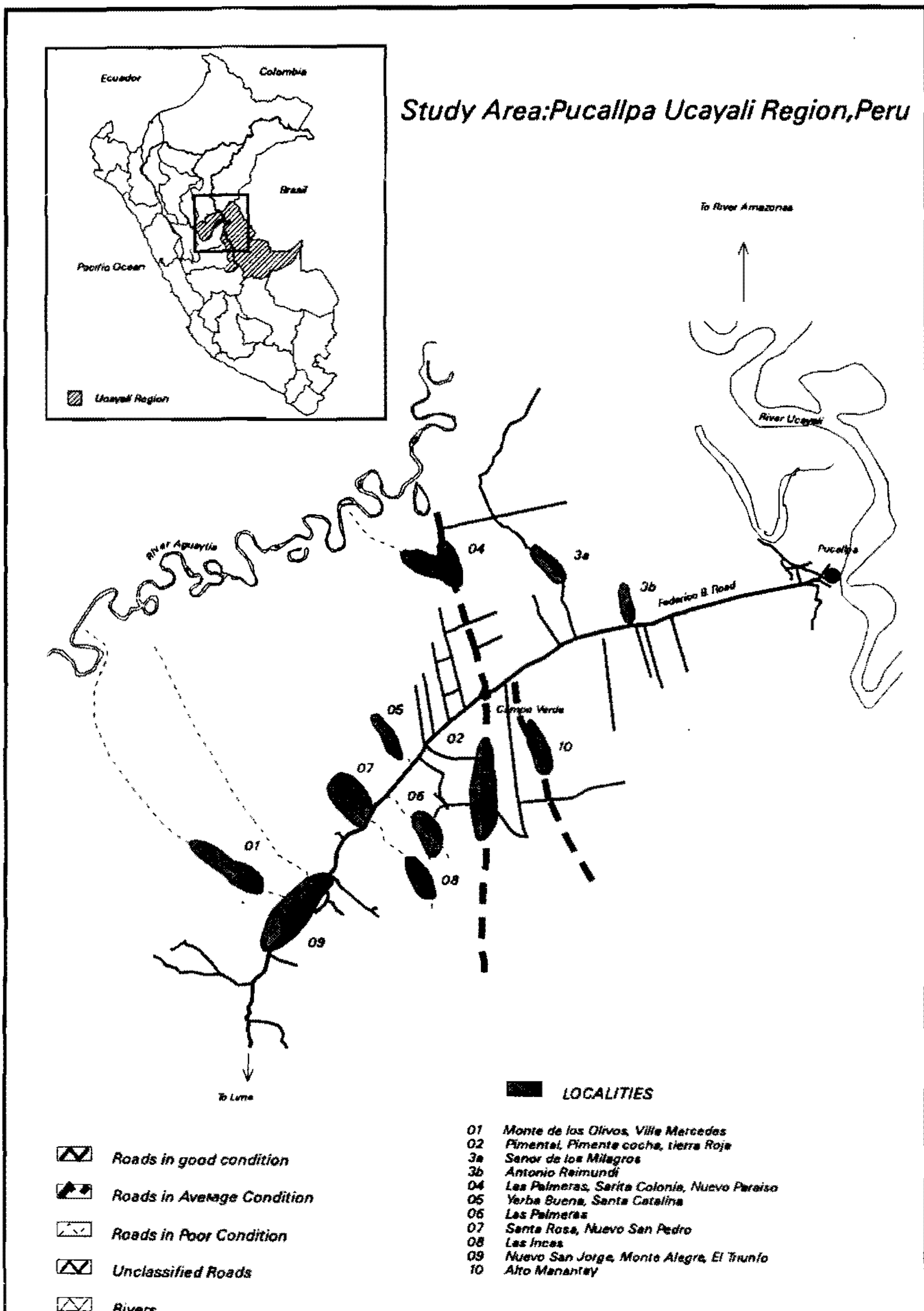
MAP 1



COLOMBIA
ECUADOR
LORETO
BRAZIL
BOLIVIA
CHILE
SOUTH
PACIFIC
OCEAN
TUMBES
PIURA
AMAZONAS
LAMBAYEQUE
CAJAMARCA
SAN MARTIN
LA LIBERTAD
ANCASH
HUANUCO
PASCO
UCAYALI
JUNIN
LIMA
MADRE DE DIOS
CUSCO
HUANCAVELICA
AYACUCHO
APURIMAC
ICA
PUNO
AREQUIPA
MOQUEGUA
TACNA
Amazon
Iquitos
Tumbes
Talara
Sullana
Piura
Paita
Chiclayo
Chachapoyas
Moyobamba
Tarapoto
Yurimaguas
Cajamarca
Trujillo
Salaverry
Chimbote
Huaraz
Pucallpa
Tingo María
Huánuco
Cerro de Pasco
Huacho
Lima
Callao
Huancayo
Huancavelica
Ayacucho
Abancay
Quillabamba
Machupicchu
Cusco
Puerto Maldonado
Pisco
Ica
Nazca
Juliaca
Puno
Arequipa
Matarani
Moquegua
Ilo
Tacna
Arica
Desaguadero
La Paz
Leticia
Benjamin Constant
Cruzeiro do Sul
Cobija
Peru
International boundary
Department boundary
National capital
Department capital
Railroad
Road
Callao is the capital of the Constitutional Province of Callao which has the status of a department but is too small to be shown on this map.
0 100 200 Kilometers
0 100 200 Miles


UCAYALI REGION
PERU
LORETO DEPARTMENT
Pucallpa
Road To Lima
PADRE ABAD
BRASIL
CORONEL PORTILLO
HUANUCO DEPARTMENT
PASCO DEPARTMENT
ATALAYA
PURUS
Alto Purus River
JUNIN DEPARTMENT
MADRE DE DIOS DEPARTMENT
CUZCO DEPARTMENT
Ecuador
Colombia
Brasil
Pacific Ocean
Ucayali Region

MAP 2



MAP 3

Esc 1:500000

Box 1. Summary History of Ucayali

- Since ~5,000 YBP: Amazonian cultures. Hunting-gathering and low-intensity shifting agriculture. Occasional contacts with Andean civilizations and Spanish conquerors.
- 1880s - 1930s: Rubber boom. Foundation of Pucallpa (1888).
- 1940s: Road Lima-Pucallpa (1943). Spontaneous colonization from the highlands.
- 1950s: Timber extraction stimulates colonist encroachment. Improvement of road to Lima. Major colonization waves by the end of the period.
- 1960s - 1970s: Agro-silvan economy develops. Subsidy from nature. Cattle numbers increase.
  - 1965 - 1975: Peruvian Amazon: Fur and live animal trade.
  - 1970 - 1972: Peru: Nationalist military government re-distributes land.
- 1980s: Coca boom. Nation-level economic crisis (hyperinflation) and terrorist guerrillas. Generalized abandonment of lands (cattle numbers decrease).
- 1990s: Control of economic crisis and terrorism. Land re-privatization. Declines in coca production (?). Reclamation of abandoned farms (?)

Box 2. R&D Institutions in Ucayali

- NARs
  - IVITA: Cattle production (since ~1983, small producers)
  - INIA: Cattle production, agroforestry, silviculture
  - IIAP: Research in natural resources, aquaculture, and agroforestry
  - University of Ucayali: Agronomy and Forestry.
- IARDS
  - CIAT: Cattle production: forages, degraded pastures (small to medium producers)
  - ICRAF: Agroforestry
  - CIFOR: Carbon sequestration markets, management of secondary forests.
- Development Agencies
  - IDRC / CIID: Agricultural research; institutional development
  - UNDP: Oil palm (alternative development)
  - IICA-GTZ: Alternative development
  - USAID: Control of coca production

Box 3. Agricultural and NN. RR. Technology in Ucayali

- Improved grass-legume pastures for double-purpose cattle
  - CIAT / IVITA
- Agroforestry: Reforestation with timber and industrial species, alley cropping (experimental)
  - ICRAF - INIA, IIAP, Reforestation Committee, Oil Palm Grower Asso.
- Integrated Organic Farming (earthworm-compost horticulture, aquaculture, small farm animals)
  - IIAP
- Sustainable logging and Silviculture
  - INIA - INRENA - ITTO
  - CNF - Netherlands (secondary and "residual" forest)
- Region-level Sustainable Land Use Plans
  - Regional government (?)
  - Swiss cooperation / CDC-Perú
  - IIAP and other

Box 4. Pucallpa-Ucayali: Socioeconomic Synthesis

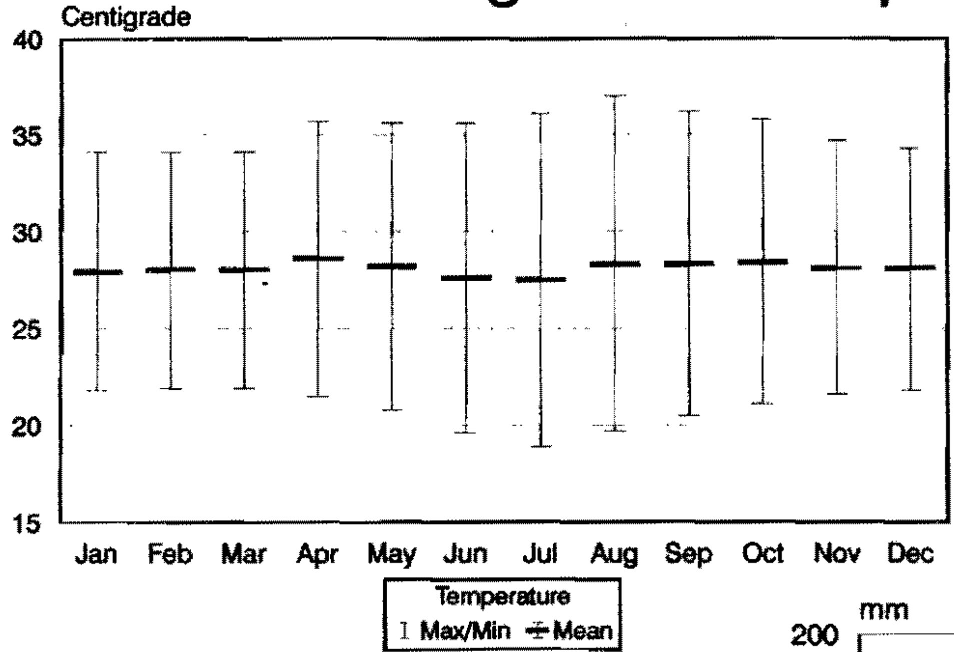
- Agricultural frontier in the Andean (Western) Amazon
  - Colonist majority, unrooted and marginal. Native cultures decimated: "Ecological blindness" (?)
  - Uncertain / Risk-prone environment (terrorism!): Risk aversion.
  - Subsidy & Boom-oriented economy (coca!): Opportunism.
    - Subsidy from nature: timber, fish, game.
  - Diversified and uncertain production. (Increasing agricultural prod.?)
  - Low institutional development. Particularly at grassroots.
  - Low market development. Extra-regional dependency (?)
  - Extractive, extensive, low-technology production.
  - Labor and capital scarcity (?)
  - High relative poverty, urban-concentrated; although livinghood better than in highlands and larger cities.
- Perú: Macro-economic bonanza. Neo-liberal policies. Latent social violence.
- World: New attitudes and possibilities for holistic R&D and sustainability.

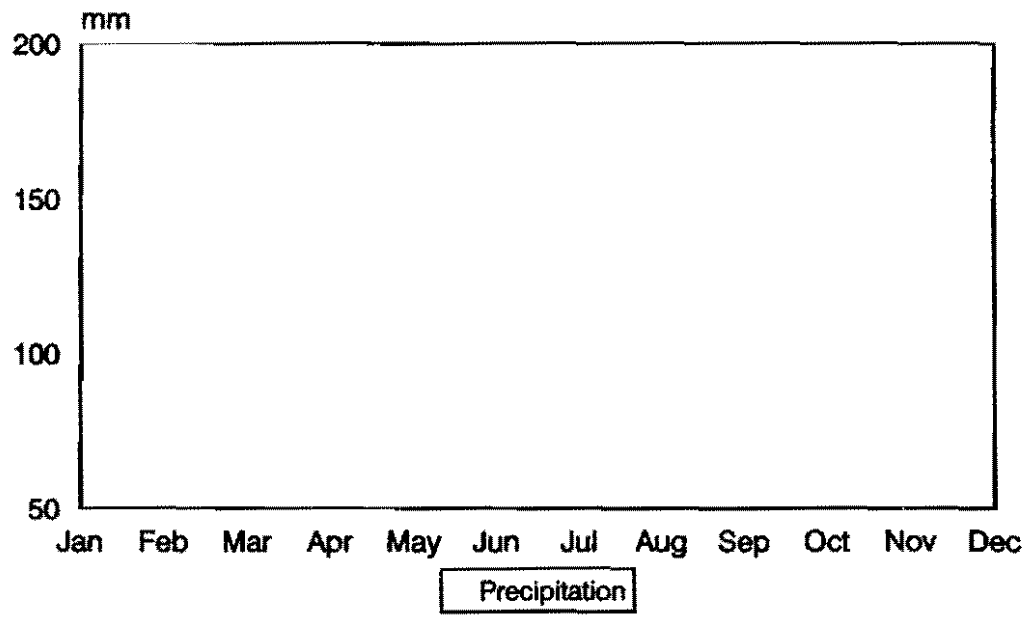
Box 5. Pucallpa-Ucayali Ecological Synthesis

- Extensively exploited old-growth forests, defaunated and wood-impoverished (genetically eroded).
- Slowly increasing deforestation (carbon emissions).
- Encroaching secondary growth and low-productivity pastures in most densely human-populated area.
- Extensive loss of productive capacity and economic value of land.
- Increasing uncontrolled fresh-water fisheries. Severe risk of over-exploitation.
- The only region in the Peruvian Amazon without protected areas. Three areas in Ucayali considered of highest conservation priority (FANPE 1996).
- Pucallpa area considered environmentally critical based on deforestation, top soil erosion and water pollution (UNCED 1992).

Sources: Gonzales 1995 in Hajek. / FANPE, 1996. Biodiversidad Biológica del Perú.

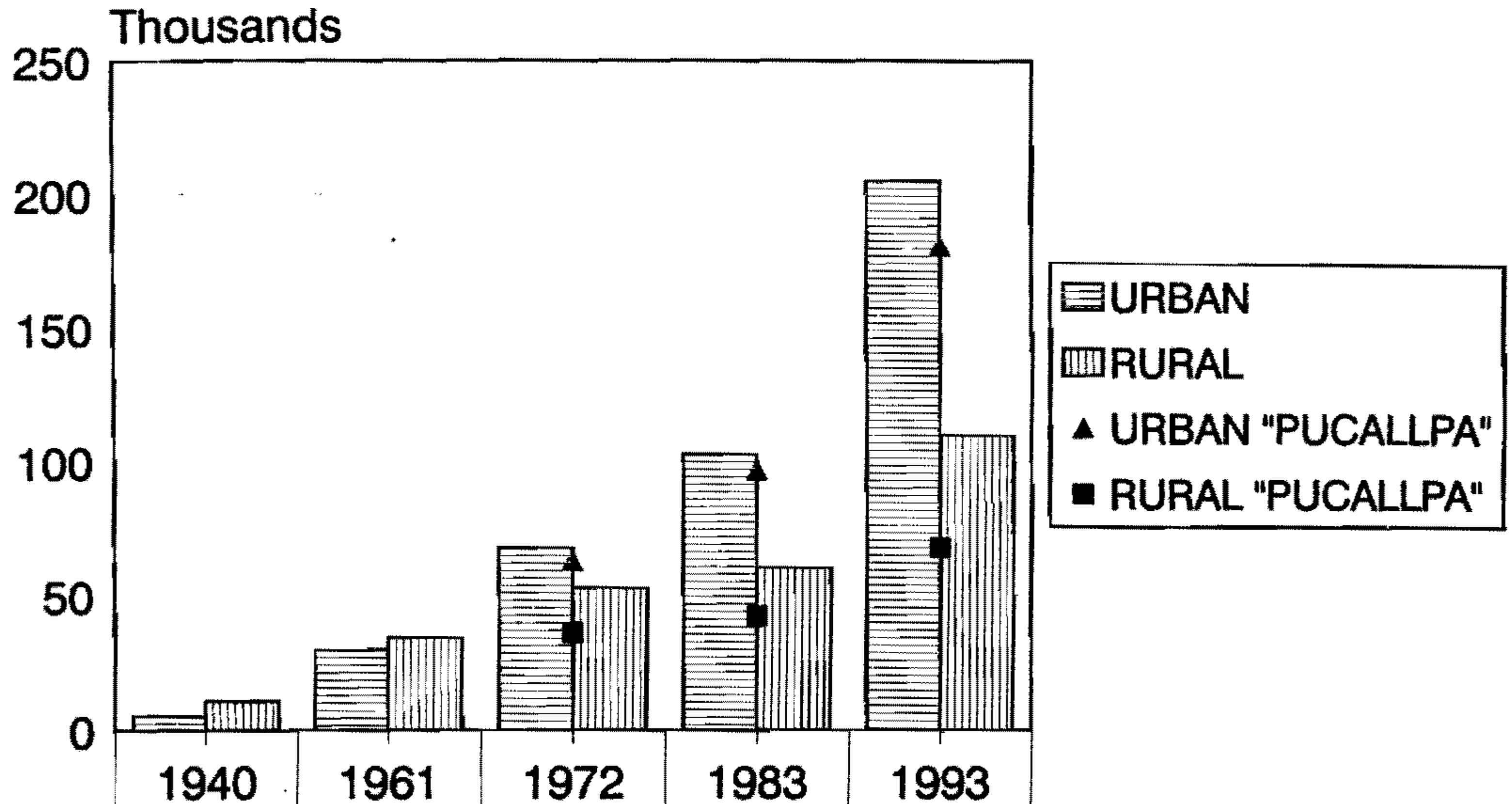
Figure 1. Pucallpa-Ucayali Climate





Source: Temperature: IVITA (1976-1981 averages). Precipitation: CIAT (25-year averages).

Figure 2. Ucayali: Demography

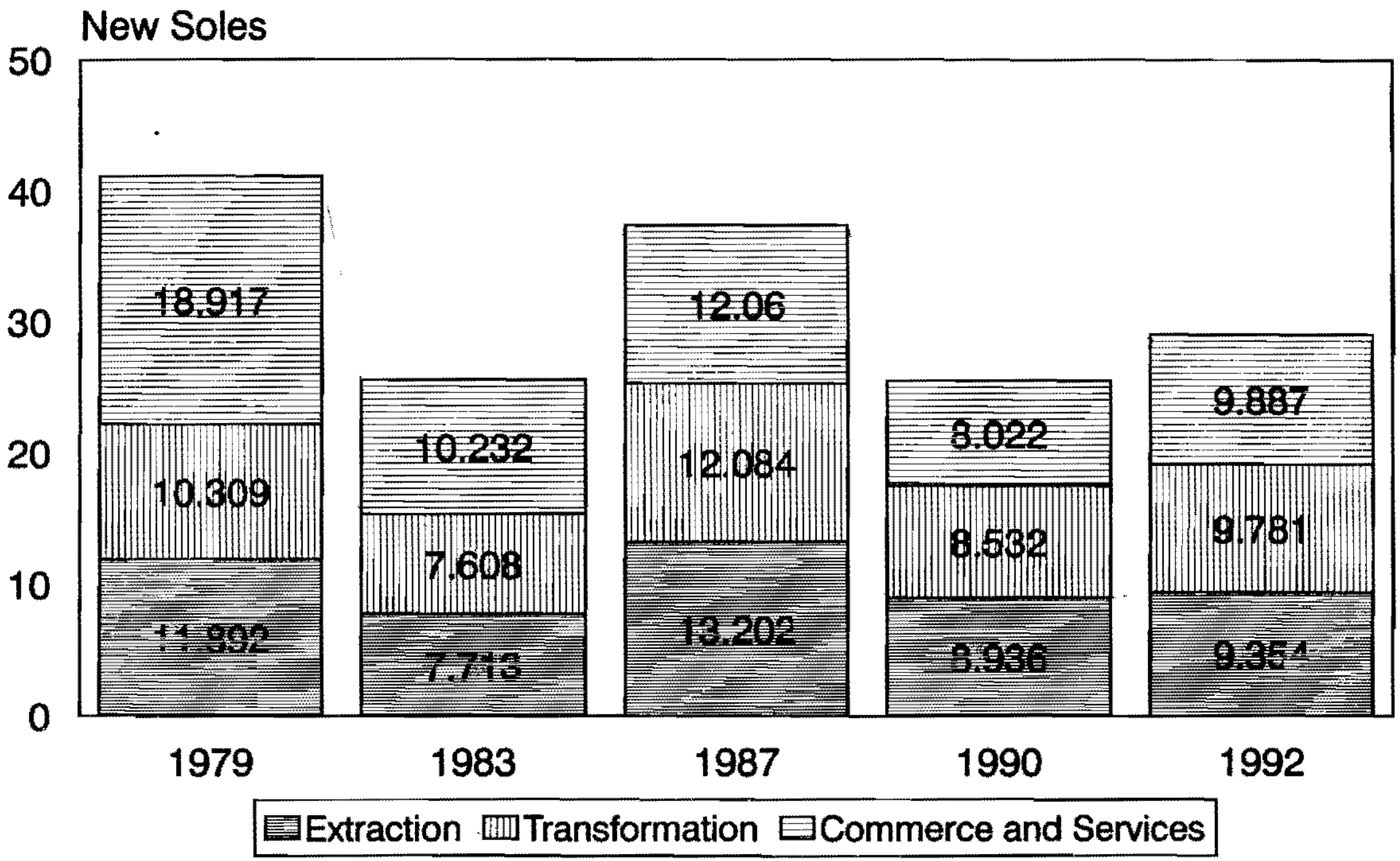


	1940	1961	1972	1983	1993
URBAN	5.332	29.724	67.675	102.66	204.795
RURAL	10.822	34.437	52.826	60.548	110.015
URBAN "PUCALLPA"			62.848	96.692	180.664
RURAL "PUCALLPA"			36.107	42.097	67.785

Source: INEI, 1994. Departamento de Ucayali: Perfil Socio-demográfico. Lima. (c. 1.6 & 1.7).

Figure 3. Ucayali: Economy

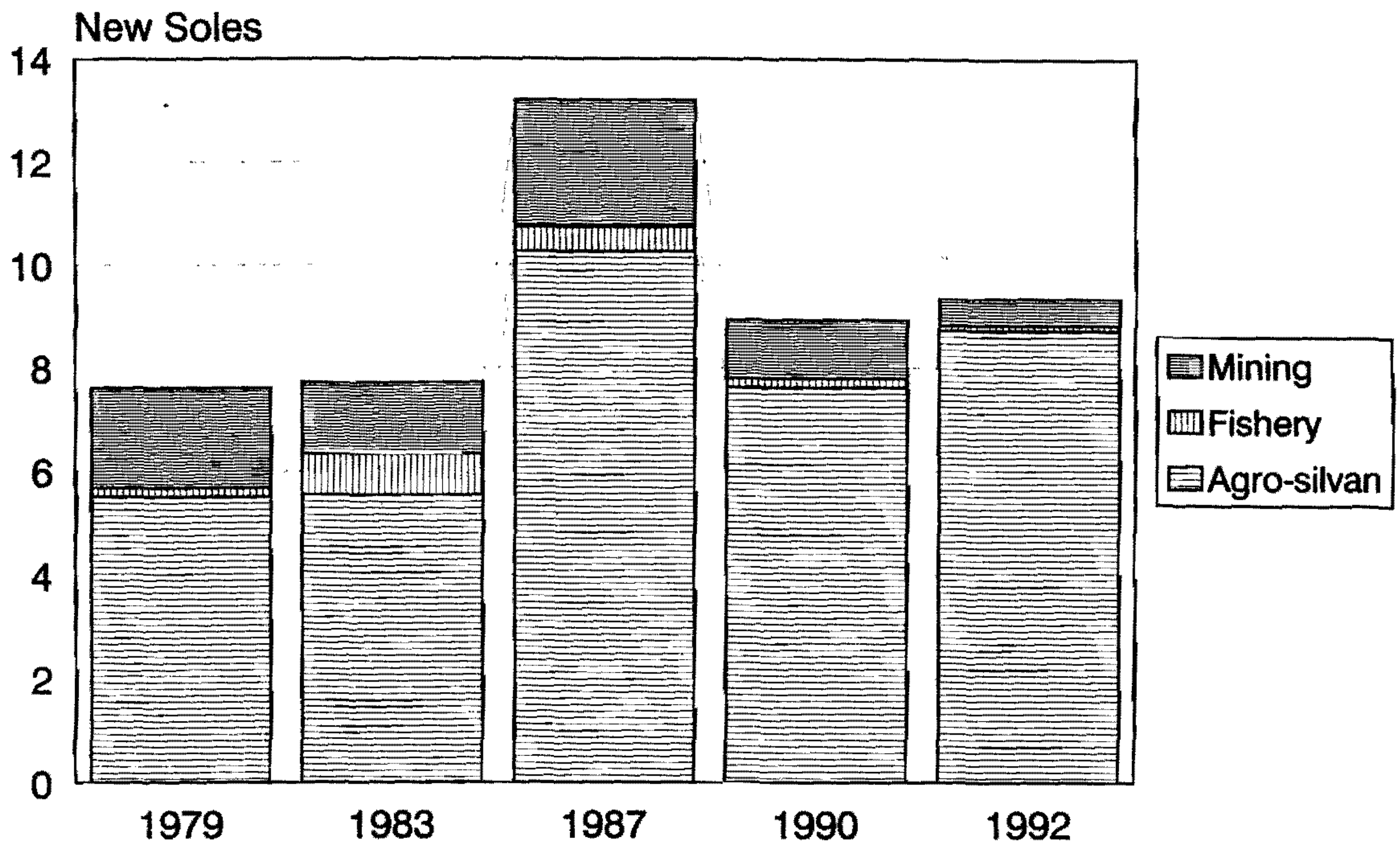
GDP (1979 Constant Prices)



Source: INEI. 1993. Cuentas Regionales Ucayali.

Figure 4. Ucayali Economy: Extraction Sector

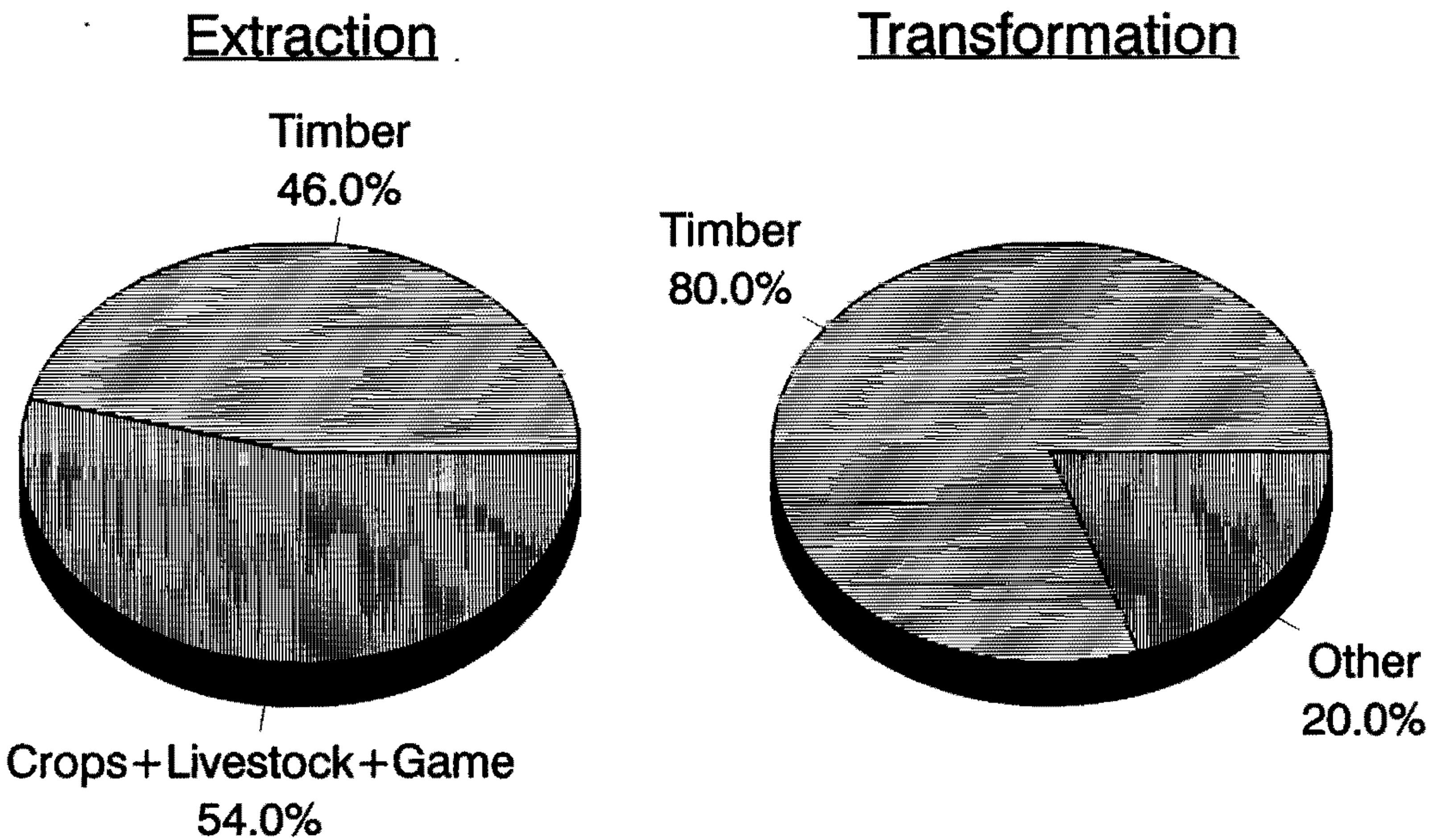
Sectorial GDP (1979 Constant Prices)



Source: INEI 1993. Cuentas Regionales Ucayali

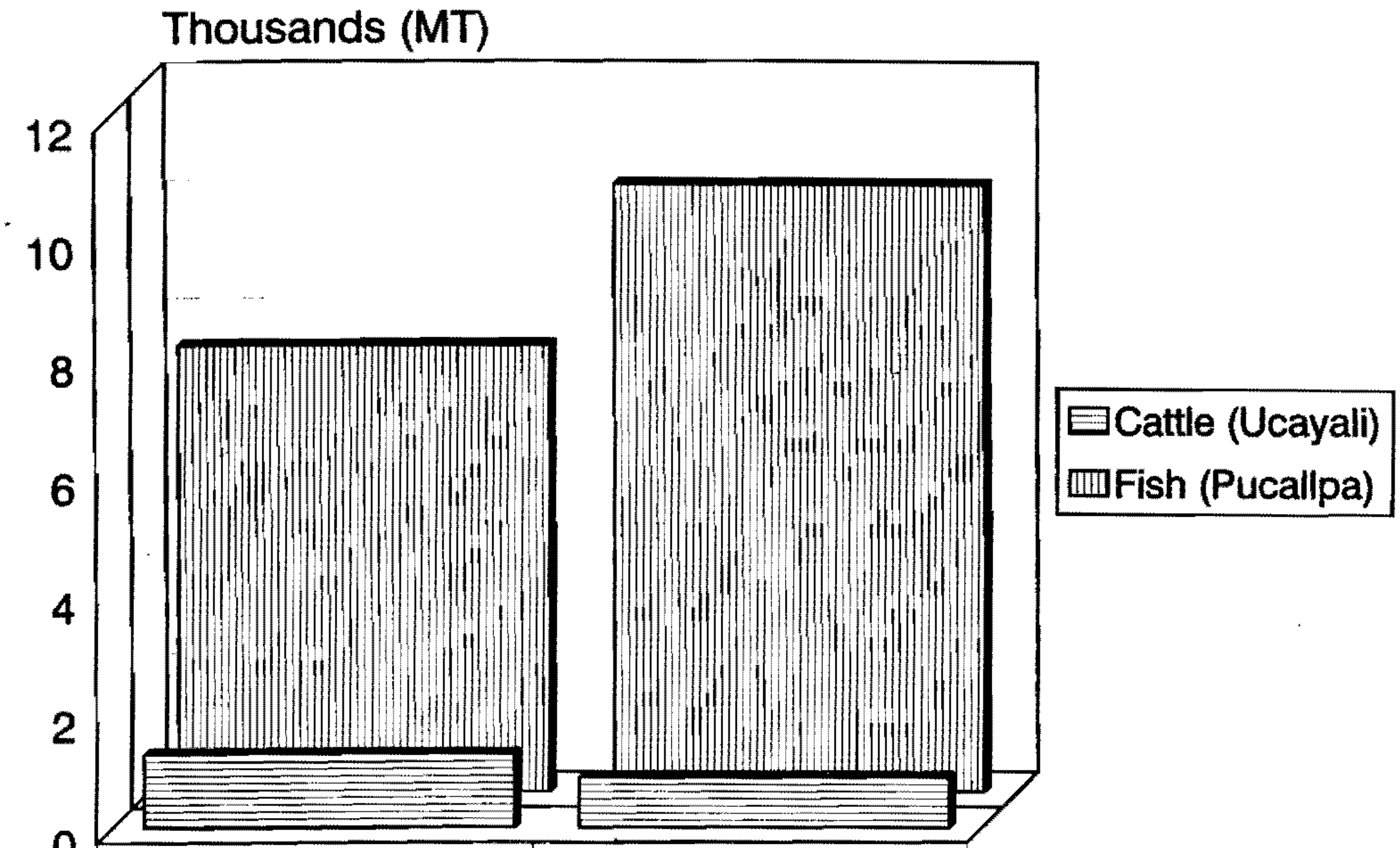
Figure 5. Ucayali Economy: Importance of Timber

Contribution to 1982's Sectorial GDPs



Source: INFOR. 1986. Diagnóstico de la Actividad Forestal del Departamento de Ucayali.

Figure 6. Ucayali: Animal Protein Production



	1989	1995
Cattle (Ucayali)	1.238	0.843
Fish (Pucallpa)	7.534	10.2546

Sources: Proyecto de Capacitación, Extensión y Divulgación Forestal, 1991. Temas Forestales No. 11./ Dirección Regional Agraria - Ucayali 1995. Anuario Estadístico./ Saavedra, 1996 (MS). Diagnóstico de la act. pesquera en la regfión Ucayali.

Figure 7. Land-Use Transformations in the Ucayali Region

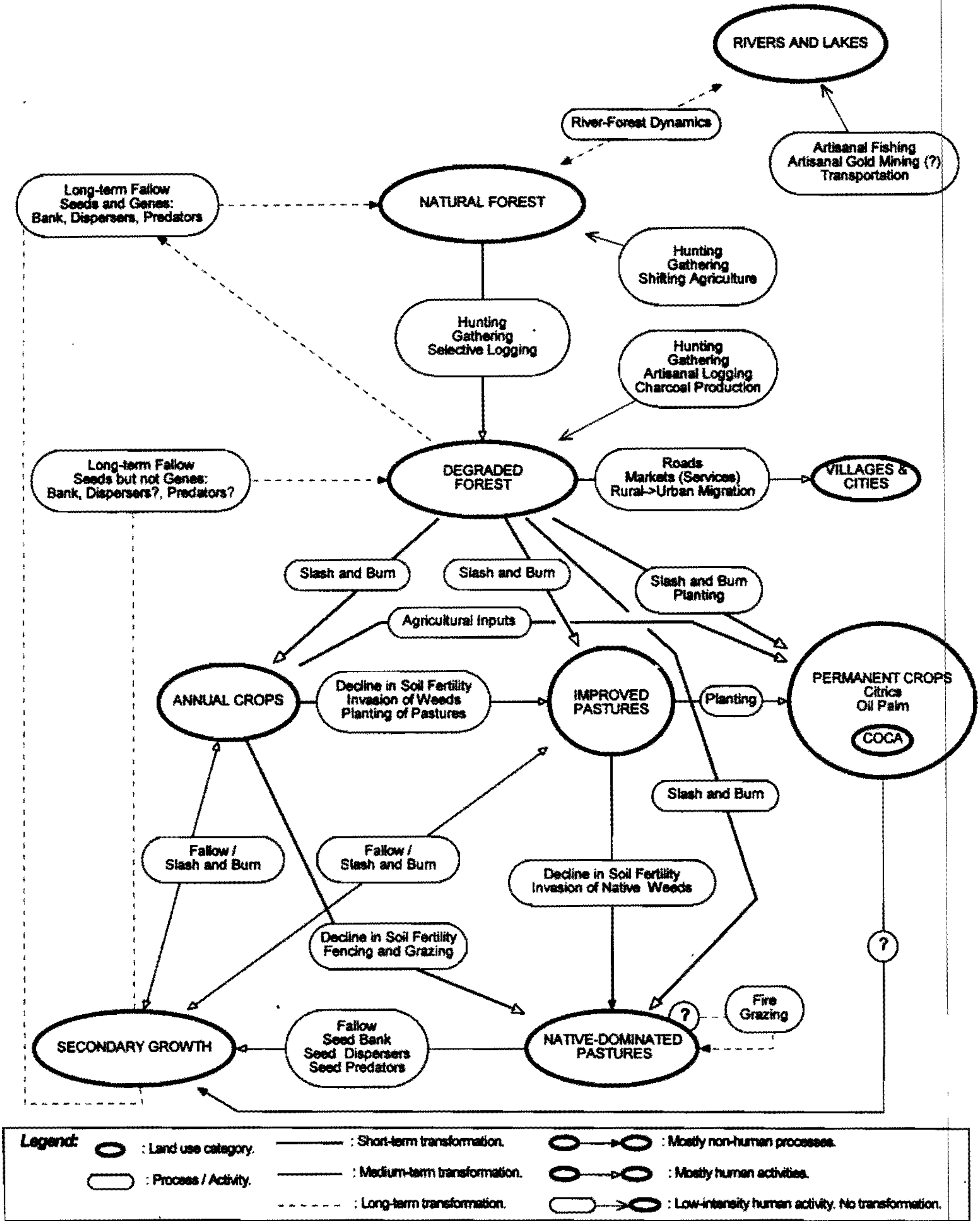


Figure 8. Land-Use Pathways in the Ucayali Region

Relative Importance by Frecuency of Occurrence

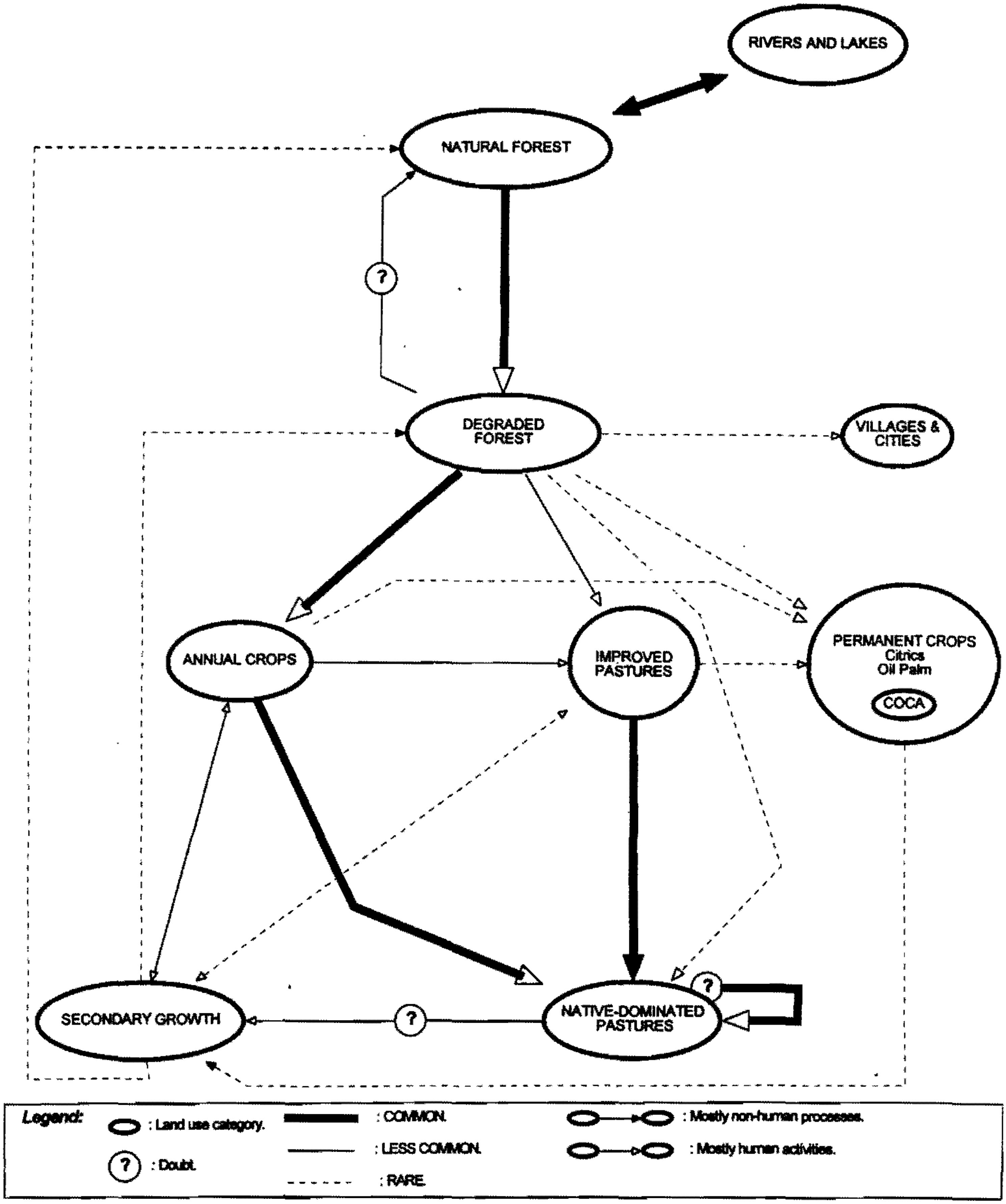
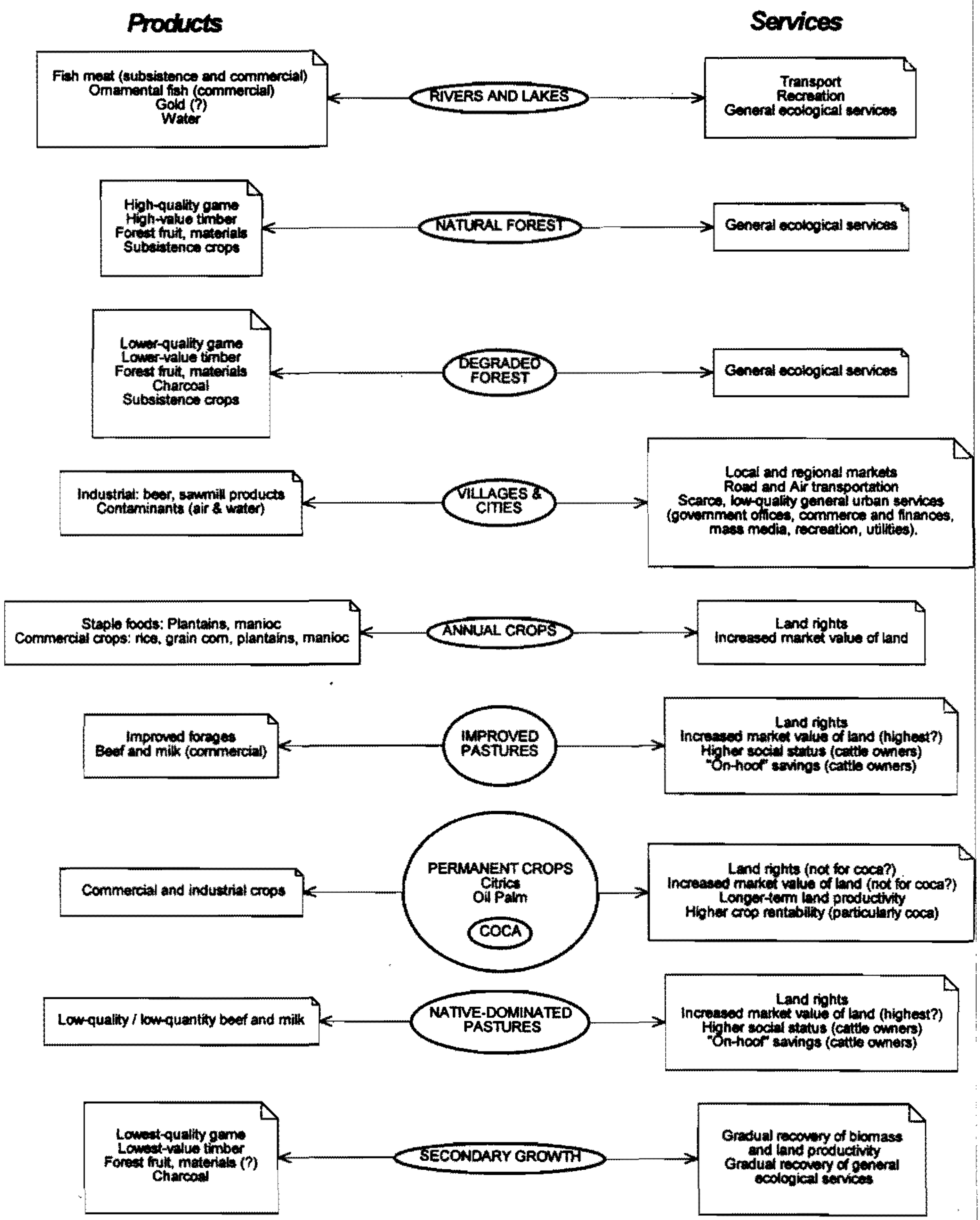


Figure 9. Main Products and Services by Land-Use Category in the Ucayali Region



Overview of the Fisheries in Ucayali

Draft, May 1997

A. General Characteristics (see hydrological map of the region):

- Ucayali region contains 14% of the entire area of inundation in the Peruvian Amazon.
- The area of influence of the fishing fleets of Pucallpa cover 60% of the Ucayali river.
- In 1986 it was estimated that the Pucallpa fleet was able to extract 20,000 tons of fish per year.
- The lakes and ox-bos are the most intensively fished, second are the gorges, rivers and pools or arms of the rivers.
- There are three main ports: in Pucallpa they include Puerto de la Capitania, in the flood season, and during the dry season, Puerto de la Hoyada. All year round there is a port in Yarinacocha, Puerto Callao.

B. Economics of the Fishery Sector

Figure 1 shows the fluctations in the volume of fish caught over the past 15 years. The instability in the quantities of fish caught and unloaded in the Pucallpa ports is most evident. The consumption of fish per capita is increasing. In 1984 was estimated at 29-32 kg /person/year Figure 2 contrasts the role of fish versus other meats as a source of protein. It would appear that the importance of fish in the rural areas is the most critical.

There are large fluctuations in price depending on the season, the time of day and supply and demand. In the commercial fishery there exists several intermediaries who ultimately elevate the price by 50% as it is distributed from the port to the consumer.

Productor --- Processor ---- Wholesaler ---- Retailer ---- Consumidor

C. Key Characteristics of the Ucayali River

- White water and low transparency
- 1460 km from Atalaya to Nauta
- Width in flood is 559m, in the dry season is 535m
- Average flow in flood is 17,305 m3/sec, in the dry season is 3,234 m3/seg
- Average Velocity; 2.01 m/sec in flood and 0.63 m/sec in dry season
- Variation in water level is +/- 10m

These major fluctuations in water level affect two important components:(i) river bed (ii) flood plain. Flooded areas are covered with dense forest resistant to flooding which play an important role in the overall productivity of the system.

Figure 1.

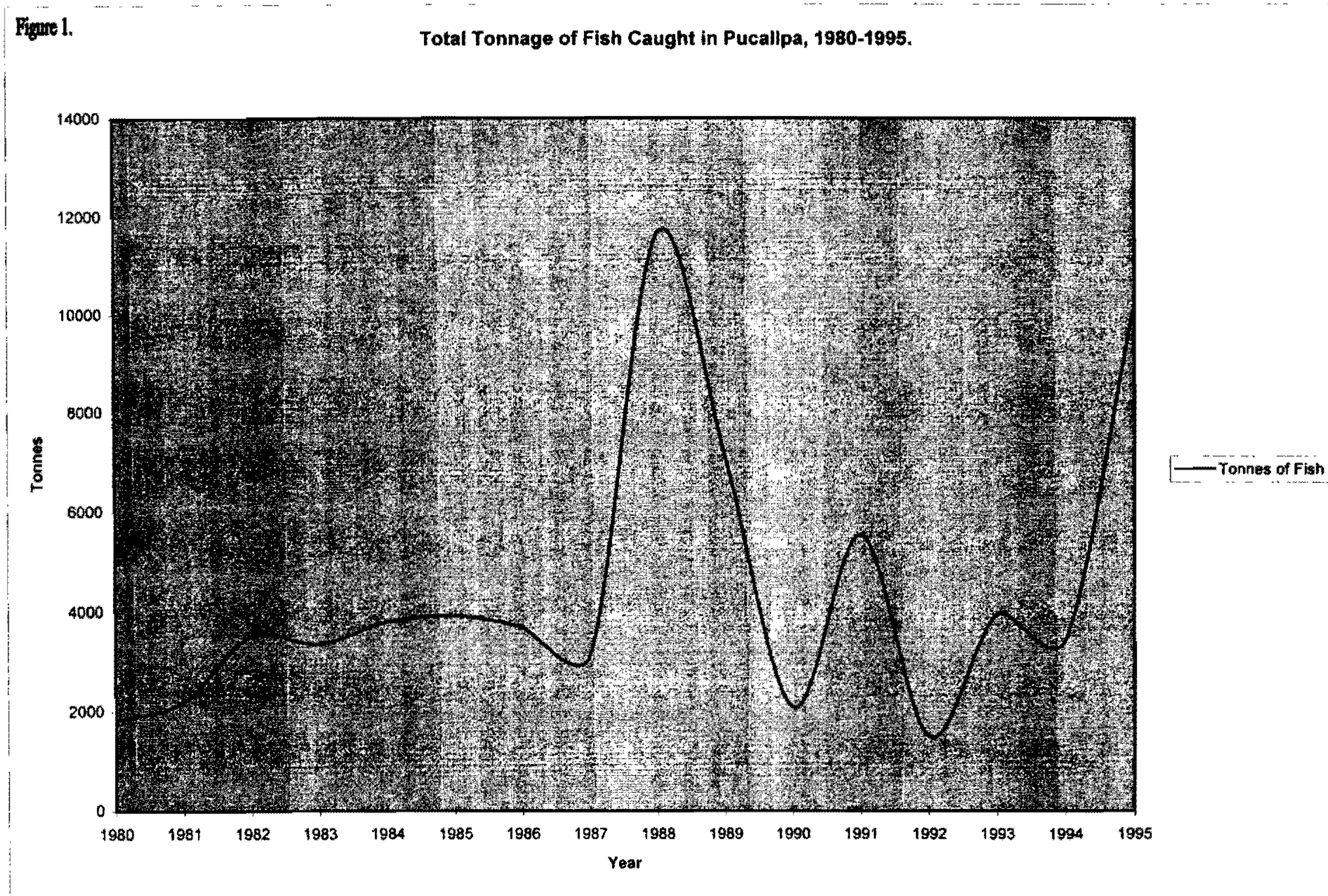
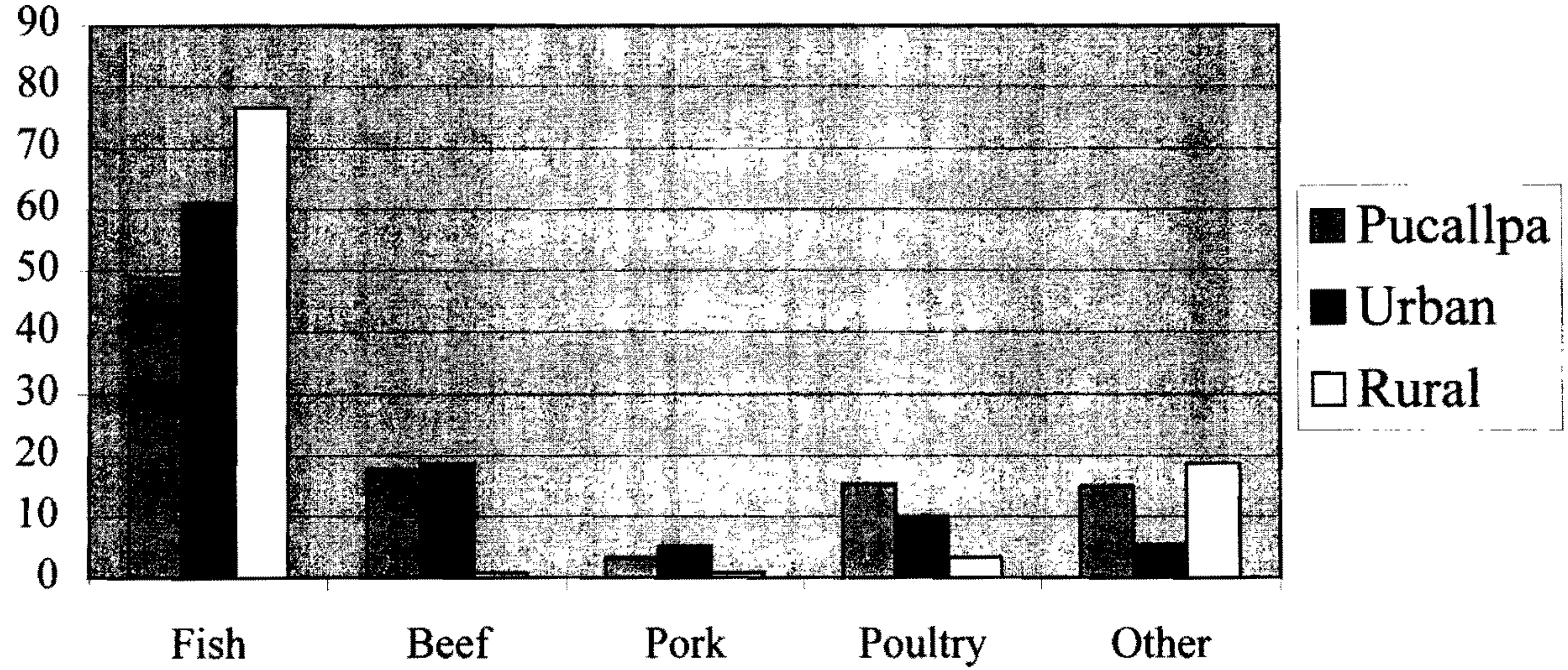

Total Tonnage of Fish Caught in Pucallpa, 1980-1995.
14000
12000
10000
8000
6000
4000
2000
0
Tonnes
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
Year
Tonnes of Fish

Figure 2.

Percentage of Meat Consumed in the Lower Jungle



Source: ENCA, 1972, in Ortega et al, 1986.

- The vegetation provides diverse habitats for animals and plants. However deforestation along the rivers banks affects the feeding and spawning of fish during the flood season. This is especially true in Yarinacocha.
- The vegetation acts as a filter for aloctonos and autoctonos material which serves as nutrients for plant communities and fish
- It forms detritus that provides food for other organisms
- Fish species are adapted to deal with fluctuations in the availability of oxygen
- In the flood plain there are many lagoons and ox-bo lakes which sustain a large part of the fishing activities
- Nutrients are concentrated in the sediment after flooding
- Soil fertility levels are markedly higher in the flood plain than in the higher areas. Thus the river plays a critical role in maintaining and renewing the productive capacity of the land. (As shown in Table 1 below the soils are more fertile in the flooded areas, whereas in the higher lands soil acidity and low levels of the key chemicals are severe limiting factors for agriculture)

Table 1: Chemical characteristics of soils representative of Ucayali

	Depth (cm)	pH	Ca	Mg	K	Sat Al.	P
Alluvial lands	0-20	7.7	27.2	3.1	.47	0	15
Highlands	0-20	4.4	.7	.3	.08	81	2

Source: ONERN, 1982

The hydrological cycle is the key determinant of the seasonality of both farming and fishing activities. Fishermen are well adapted to these fluctuations and concentrate their activities in different places depending on the season. During flood fishing is mainly in the lakes, in between they use "canos" and gorges, in dry season the fishermen are in the rivers where the fish accumulate as they leave the flooded areas. Figure 3 highlights the link between the different cycles of farming and fishing and the hydrological cycle.

D. Characteristics of Fish Resources

There are roughly 1200 to 2500 species in the Peruvian Amazon (Bolke et al. 1978; Nelson 1984; Gery 1984)

The high diversity and wide range is because of two factors:

- Large number of habitats
- Major changes in the water level create many ecological niches, causing specialization and speciation.

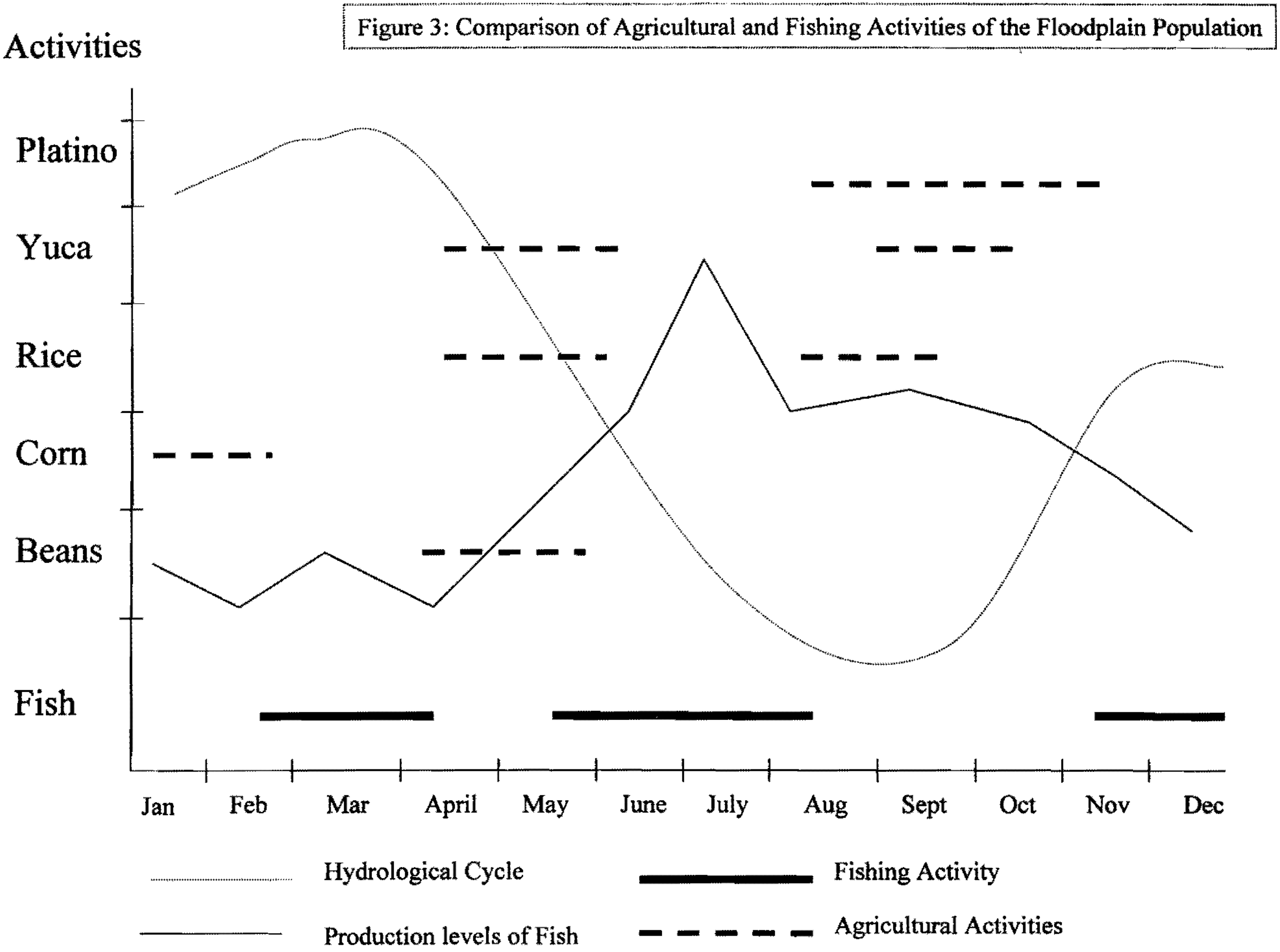


Figure 3: Comparison of Agricultural and Fishing Activities of the Floodplain Population
Activities
Platino
Yuca
Rice
Corn
Beans
Fish
Jan
Feb
Mar
April
May
June
July
Aug
Sept
Oct
Nov
Dec
Hydrological Cycle
Fishing Activity
Production levels of Fish
Agricultural Activities

There are 378 registered species in Ucayali. Sixty-four are caught for consumption. Seventy-four are caught for ornamentals (ie. for aquariums mainly in the international market). Of the 64 species consumed, 10 species sustain 80% of the fishery production (See Figure 4). The iliofagos fish which eat detritus and algae comprise 50% of the total volume of catches

Seven Main Fish Families Exploited:

(i) *Arapaimidae*: Biggest species found in sweet water, "el paiche". The population has diminished to the point where they have not existed in Yarinacoche for 13 years. They are still found in Iparía and Tahuanía. They inhabitat slow waters.

(ii) *Characidae*: Has the most number of species, for both consumption and ornamentals. It is of major importance for aquaculture.

(iii) *Prochilodontidae and Curimatidae*: Eats the detritus and microalga. Comprise 50% of the commercial production "boquichico and chio-chio"

(iv) *Doradidae*: Exploited for both consumption and ornamentals

(v) *Pimelodidae*: Second most important commercial fish

(vi) *Loricariidae*: Ornamental and consumption

(vii) *Cichlidae*: Typical fish typical of tranquil waters

E. Characteristics of the Fishermen

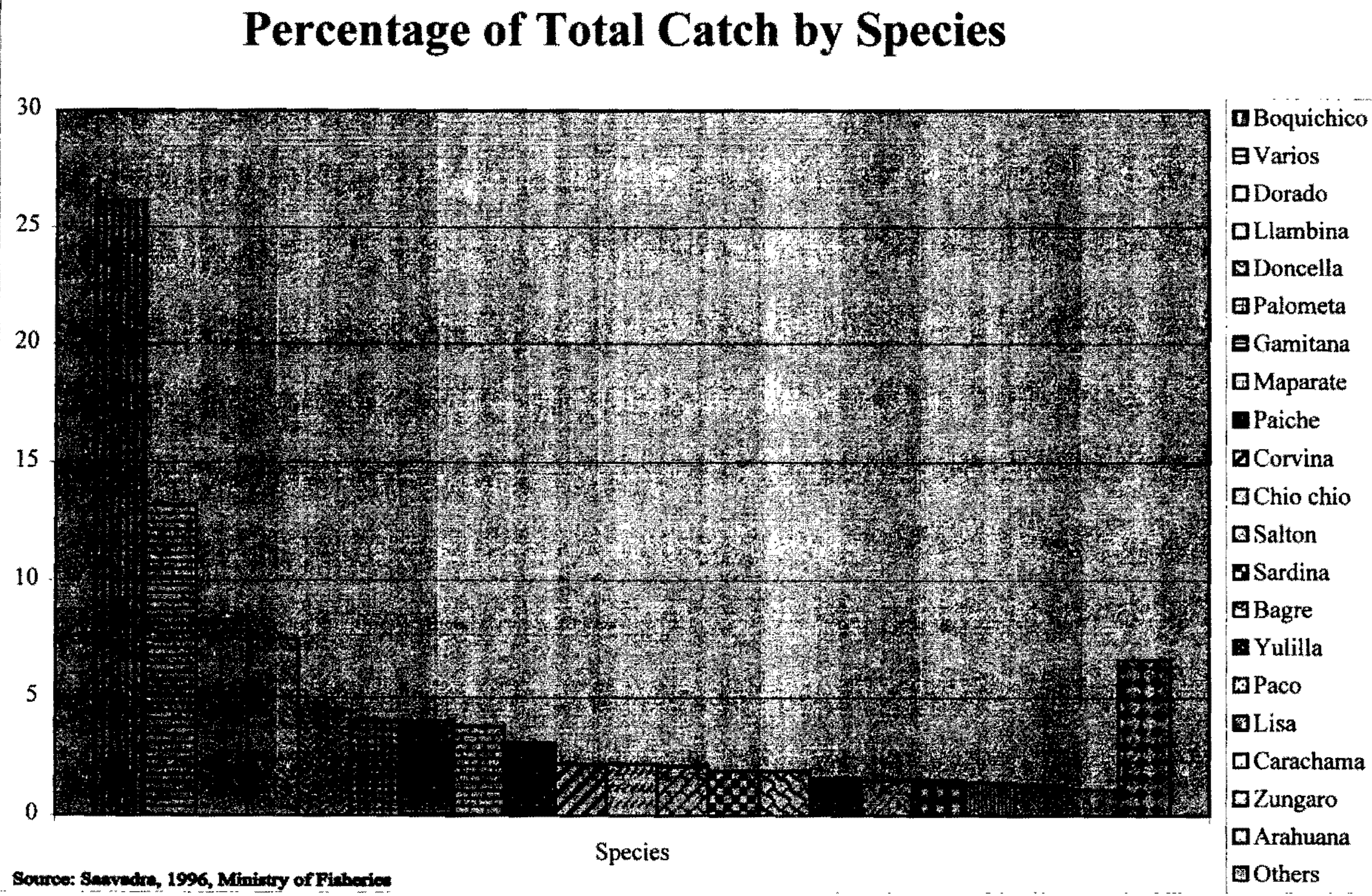
In the Pucallpa area most fishermen dedicate the majority of the work to fishing

There are three types of fishermen:

(I) Professional/full-time fishermen

- principle and only activity is fishing
- have boats with motors and commercial nets
- located mainly in Pucallpa and Yarinacocha
- called "congeleros"
- can travel far distances

Figure 4.



Source: Saavedra, 1996, Ministry of Fisheries

(II) Semiprofessional/part-time fishermen

- commercial scale but only during the dry season when fish are most plentiful
- sell fish in Pucallpa
- in flood season fishing is for subsistence only
- has complementary activities in agriculture
- has motors and commercial nets
- located in Atalaya, Aguaytía, Esperanza and especially Masisea

(III) Artisanal fishermen (subsistence)

- fish to sustain their families
- in general are agriculturists
- fish all year round
- canoes and oars
- located in small caserios, native communities and in come small centres such as iparia, San Alejandro and Esperanza

F. Organizations in the Sector

(i) IVITA (Instituto Veterinario de Investigaciones Tropicales y de Altura): Responsible for fishery research

(ii) Provincial Congress of Coronel Portillo: Assume control of the market price for fish. Maintain a registry of stored and processed fish.

(iii) DIREPE VII-Pucallpa: Representative of the Ministry of Fisheries

(iv) CORDEU (Corporación de Desarrollo del Departmento de Ucayali): Organization that finances projects , supports various studies and activities that attempt to diagnose the state of the fisheries. Promote aquaculture and support the artisanal fishermen.

(v) IIAP:(Insitituto de Investigaciones de la Amazonia Peruana): Finances research projects in different areas of the Peruvian Amazon.

(vi) Capitania de Puerto: Dependent on the Ministry of Marines. They register and control the unloading of fish at the different ports.

G. The Main Issues Facing the Fishery Sector in Ucayali

(i) Lack of information on overall fisheries in Ucayali, unreliable data on exploitation and the commercialization of the fisheries and poor estimation of the potential of the hydrological resources (Eg. It is estimated that the registration of catches in the ports represents only 40% of the actual volume of fish extracted).

(ii) Fishing activities are very diversified, intensive and fluctuating depending on the cycles of the rivers.

(iii) Inefficient methods of catching, preserving, processing and selling of fish.

(iv) Inadequate legislation and control of fishing. Lack of human resources to enforce the regulations (eg.In areas where fishing is difficult, prohibited methods such as dynamite and toxic chemicals are frequently employed. This is in Atalaya and Padre Abad. In addition there is a high demand of tortoise/turtle eggs, which are being harvested at dangerously high levels. There is as yet no effective protection of this resource).

(v) Failure to prioritize investment in the sector

(vi) Necessity to increase the production of fish during the flooding period, as this is when supply is at its lowest (Aquaculture is one of the main alternatives for this low productivity period).

(vii) Lack of infrastructure for unloading, storing, freezing and distributing the resources. In the different stages of processing, transportation and storage there are few measures taken to ensure adequate hygiene and safety of the product.

(viii) Necessity of a management plan to rationally administer the fishery resources in the Ucayali.

(ix) Lack of knowledge on the complex interactions of the many different species within the watershed. For example there is little knowledge of the state of aquatic mammals and their importance within the ecosystem.

References

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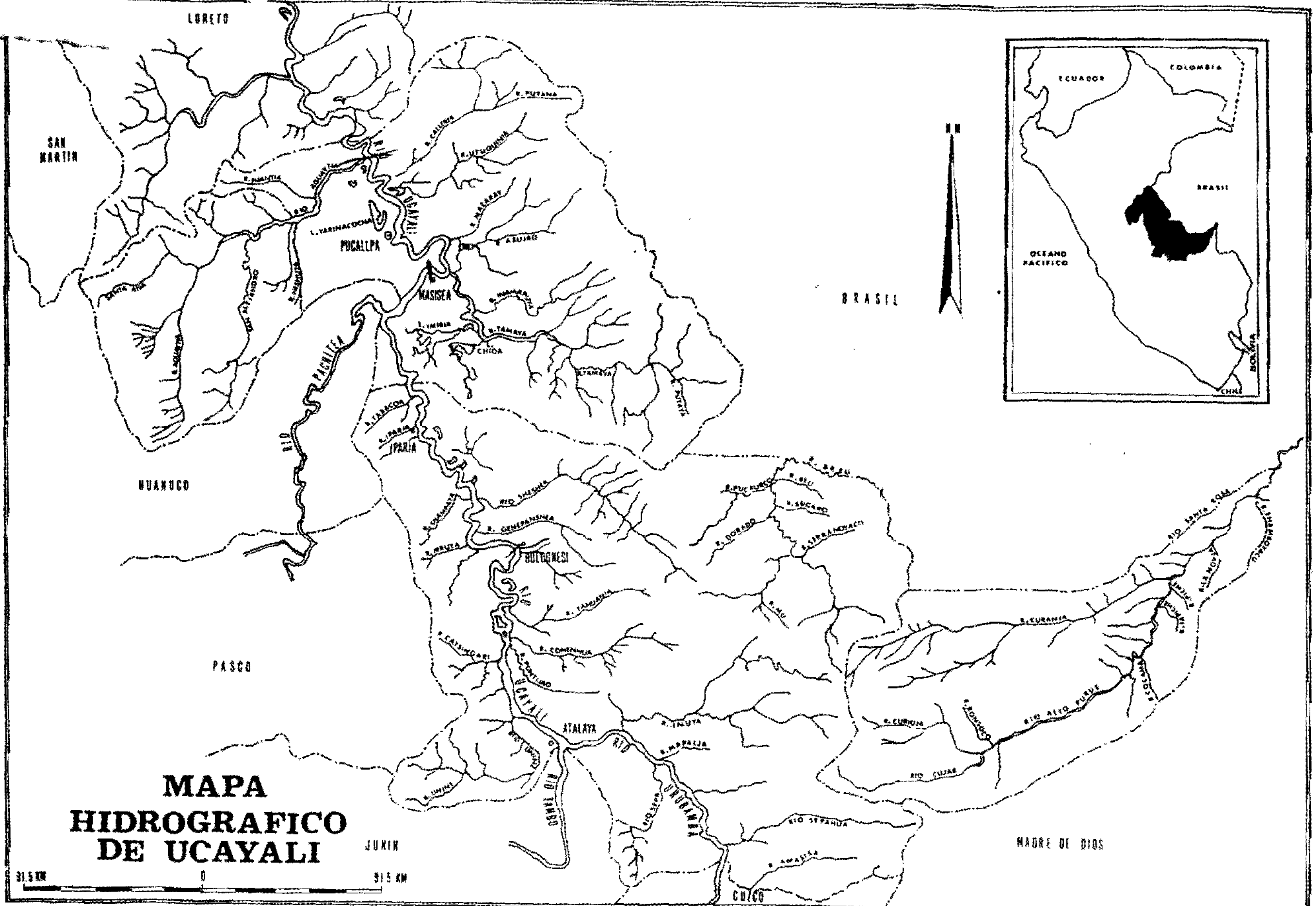
MAPA HIDROGRAFICO DE UCAYALI
LORETO
SAN MARTIN
HUANUCO
PASCO
JUNIN
CUZCO
MADRE DE DIOS
BRASIL
PUCALLPA
MASISEA
BOLOGNESI
ATALAYA
RIO UCAYALI
RIO PACHITEA
RIO URUBAMBA
RIO TAMBO
RIO ALTO PURUS
RIO CUJAR
RIO SEPAHUA
RIO SHESHEA
L. YARINACOCHA
L. IMIRIA
NM
ECUADOR
COLOMBIA
BRASIL
OCEANO PACIFICO
BOLIVIA
CHILE
31.5 KM
0
31.5 KM