Knowledge-Based Monitoring and Evaluation System of Land Use

Assessing the Ecosystem Conservation Status in the Influence Area of a Gas Pipeline in Bolivia

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A mis padres, Danila y Arnaldo

a la memoria de Esther Essayag y Fidelina de Hernandez

Summary

This dissertation develops a monitoring and evaluation (M&E) system to assess the conservation status of the forest located in the influence area of the gas-pipeline San Miguel-Cuiabá in eastern Bolivia. The M&E system sets up the basis for a prospective decision system to support local adapted management and conservation strategies. The Chiquitano dry forest is an ecosystem still close to natural conditions. In December 2000 an underground pipeline came into operation to export gas to Brazil. The gas pipeline cut through the forest and its direct impact on the vegetation cover was discernible. Less obvious are its indirect impacts, which are related to: (a) the village level compensation program (PDI), and (b) the use of the right of way as route of access into new forest areas, especially for hunting and logging activities.

The most important human activities involving the use of land in the area of influence of the gas-pipeline San Miguel-Cuiabá are: extensive farming, selective logging, hunting and fuel wood extraction, which are practiced by small villages. These activities are characterized by low levels of return, technology and commercialization. If the level of technology remains constant but demand increases, deforestation and forest degradation will grow. Indirect impacts of the gas pipeline San Miguel-Cuiabá on the Chiquitano Dry Forest are related to (a) the village level compensation program and (b) the use of the right of way as route of access into new forest areas, especially for hunting and logging activities. The combination of the gas pipeline issues with aspects of the endogenous land use forced a joint M&E program.

The M&E system was built using a combination of conventional and novel methods in six interactive phases. Both scientific knowledge and local issues of land use were integrated using knowledge engineering, fuzzy logic, and Geographic Information System (GIS) techniques. The M&E system evaluates land cover information derived from remote sensing data and land use data obtained from village-level surveys. Four components make up the system: (a) final set of conceptual factors and indicators, (b) fuzzy logic knowledge-based models for spatial evaluation, (c) validation of the system and baseline M&E, and (d) brief M&E protocol.

(a) The *final set of conceptual factors and indicators* constitutes a relevant and validated set of 17 indicators and 11 sub-indicators derived from scientific knowledge and local issues of land use obtained from village surveys.

(b) Two *fuzzy logic knowledge-based models for spatial evaluation* organize the indicators based on their interrelationship s and areas of influence. The village-level knowledge-based model includes all indicators and sub-indicators that have influence within villages. The evaluation criterion of the village-level model is: "pressure on forestlands due to extensive agriculture is maintained within acceptable limits". The meso-level knowledge-based model includes all indicators and sub-indicators with influence on the area outside the villages' limits. The evaluation criterion of the meso-level model is: "Change in conservation status of ecosystems as a result of land use, is maintained within acceptable limits".

(c) The *validation of the system and baseline M&E* shows the evaluation results. Where land cover information (2002) derived from remote sensing data is integrated with data from village-level surveys (2003). Both are evaluated by the models. The baseline results show that at village level, there is either a moderate to strong pressure on the surrounding forest due to the agricultural practices of fully extensive farming. At meso-level, quite healthy ecosystems predominate in the research area. 82.96% of the total area under research has very good conservation status and 3.67% correspond to deforested areas. 12.66% of the area shows either good (11.33%) or moderate (1.84%) conservation status, and only 0.19% shows a poor level;

(d) Brief M&E protocol describing the most important issues to consider when performing M&E tasks. The execution of the M&E process takes around 5 months and is divided in three phases: (a) general organization, (b) data collection and (c) results reporting. The minimum staff required is 4: a coordinator (environmental scientist), two field consultants (one agronomist and one person from the villages) and one office consultant (specialist in geo-informatics). For Bolivia, the total costs (without considering software) amount to approximately 8000 Euros.

The results of this dissertation provide a structured program for monitoring and evaluating the conservation status of the ecosystem in the research area. The M&E system is an understandable and logic output that considers and documents lessons learned on the field, which facilitate a successful acceptability and implementation by the end-user (FCBC). The modularity of the *knowledge-based models* enables: (a) a separate assessment of the level of pressure from each factor, identifying which human activity is causing higher impact on the ecosystem; and (b) its adaptation or expansion if (e.g.) new human activities take place within the research area. Moreover, single parts of each model can be transferred to other models in order to evaluate other forest ecosystems exposed to similar human pressures.

Zusammenfassung

Die vorliegende Dissertation entwickelt ein Monitoring- und Evaluierungs (M&E) System um den Erhaltungszustand des Waldes im Einflussbereich der San Miguel-Cuiabá Gaspipeline im Osten Boliviens abzuschätzen. Das M&E-System bildet die Basis für ein zukünftiges Entscheidungssystem für lokal angepasste Management- und Naturschutzstrategien. Der Chiquitano Trockenwald ist (noch) naturnah, doch im Dezember 2000 wurde eine unterirdische Pipeline für den Gasexport nach Brasilien in Betrieb genommen. Die Gaspipeline verläuft durch den Wald. Ihre direkten Auswirkungen auf die Vegetationsbedeckung sind deutlich wahrnehmbar. Weniger offensichtlich sind ihre indirekten Auswirkungen, die (a) auf Dorfebene das Entschädigungsprogramm der Gaspipeline (PDI) und (b) die Nutzung der Schneise der Gaspipeline als Zugangsweg in neue Waldbereiche für den Jagd und Holzgewinnung betreffen.

Die wichtigsten anthropogene Tätigkeiten, im Einflussbereich der Gaspipeline San Miguel-Cuiabá sind: extensive Landwirtschaft, selektive Abholzung, Jagd und Brennholzentnahme, welche von kleinen Dörfern ausgeübt werden. Diese Tätigkeiten sind durch ein niedriges Gewinn-, Technologie- und Kommerzialisierungs- Niveau charakterisiert. Bei gleichbleibendem Technologieniveau und zunehmendem Bedarf, werden Entwaldung und Walddegradierung zunehmen. Im Zusammenhang mit der San Miguel- Cuiabá Gaspipeline ist auf Dorfebene Entschädigungsprogramm aufgelegt worden. Weiterhin ist durch die Pipeline die Nutzung der Schneise als Zugangsweg in neue Waldbereiche für den Jagd und Holzgewinnung verbunden. Da der Bau der pipeline Veränderungen der endogenen Landnutzung mit sich bringt, ist das M&E- Programm notwendig.

Das M&E System wurde aus einer Kombination von herkömmlichen und innovativen Methoden in sechs interaktiven Phasen entwickelt. Expertenwissen sowie Information über die lokale Landnutzung wurden mit Hllfe von Wissensverarbeitung, Fuzzy-Logik und Geographischen Informationssystemen (GIS) integriert. Das M&E System wertet Vegetationsabdeckungsinformation und Landnutzungsdaten aus, die jeweils von Fernerkundungsdaten und Dorf- Ebene Interviews abgeleitet wurden. Vier Komponenten bauen das System auf: (a) ein finales Set von konzeptuellen Faktoren und Indikatoren, (b) fuzzy logic wissensbasierte Modelle für räumliche Evaluierung, (c) die Validierung des Systems und Grundüberwachung, und (d) ein kurzes M&E- Protokoll.

(e) Das *finale Set von konzeptuellen Faktoren und Indikatoren* bildet ein relevantes und validiertes Set von 17 Indikatoren und 11 Sub-Indikatoren, die von Expertenwissen und Information über die lokale Landnutzung abgeleitet wurden.

(f) Zwei *fuzzy logic wissensbasierte Modelle für räumliche Evaluierung* gliedern die Indikatoren auf Basis ihrer Zusammenhänge und Einflussbereiche: Das Dorf-Ebene wissensbasierte Modell beinhaltet sämtliche Indikatoren und Sub- Indikatoren, die innerhalb der Dörfern Einfluss ausüben. Das Evaluierungskriterium des Dorf-Ebene Modells lautet: „Der Nutzungsdruck auf die Wälder durch die extensive Landwirtschaft bleibt innerhalb akzeptabler Grenzen“. Das Meso- Ebene wissensbasierte Modell beinhaltet sämtliche Indikatoren und Sub- Indikatoren, die außerhalb der Dorfränder Einfluss ausüben. Das Evaluierungskriterium des Modell lautet: „Die Änderung des Erhaltungszustandes des Ökosystems auf Grund der Landnutzung bleibt innerhalb akzeptabler Grenzen“.

(g) Die *Validierung des Systems und die Grundüberwachung* stellen die Evaluierungsergebnisse dar. In dieser Komponente werden Lanbedeckungsinformationen (2002) -abgeleitet von Fernerkundungsdaten- und Landnutzungsdaten (2003) erhalten aus Dorf- Ebene Interviews- integriert. Beide werden durch die Modelle evaluiert. Die Grundüberwachungsergebnisse zeigen, dass auf Dorf- Ebene der Nutzungsdruck auf die Wälder durch extensive Landwirtschaft entweder gemäßigt oder stark ist. Auf Meso- Ebene herrschen im Untersuchungsgebiet ziemlich intakte Ökosysteme vor. 82,96% des gesamten Untersuchungsgebietes hat einen sehr guten Erhaltungszustand und 3,67% sind abgeholzt. 12,66% des Untersuchungsgebietes zeigt einen entweder guten (11,33%) oder gemäßigten (1.84%) Erhaltungszustand, und knapp 0,19% sind stark geschädigt.

(h) Das kurze *M&E- Protokoll* beschreibt die wichtigsten Aspekte, die bei der Durchführung von M&E- Tätigkeiten betrachten werden müssen. Die Durchführung des gesamtes M&E- Prozess benötigt ca. 5 Monate und ist in drei Phasen aufgeteilt: (a) Allgemeine Organisation, (b) Datensammlung und (c) Berichterstattung der Ergebnisse. Erforderlich sind mindestens vier Mitarbeiter: ein Koordinator (Umweltwissenschaftler/in), zwei FeldmitarbeiterInnen (ein Landwirt/in und ein Bewohner/in der Dörfern) und ein Büromitarbeiter/in (Spezialist in Geo- Informatik). Für Bolivien beziffern sich die gesamte Kosten (ohne Softwareaufgaben) auf ca. 8000 Euros.

Die Ergebnisse dieser Doktorarbeit bieten ein strukturiertes Programm für Monitoring und Evaluierung des Ökosystemerhaltungszustandes im Untersuchungsgebiet an. Das M&E-

System ist ein verständlicher und logisches Output, der die im Feld gesammelten Erfahrungen betrachtet und dokumentiert, und dadurch die Akzeptanz und Implementierung bei dem Endnutzer (FCBC) ermöglicht. Die Modularität der *wissensbasierten Modelle* erlaubt: (a) eine unabhängige Einschätzung des Drucks auf jeden einzelnen Faktor, sodass eine Identifizierung der anthropogenen Tätigkeit, die die höchsten Auswirkungen auf das Ökosystem hat, möglich ist. Außerdem erlaubt die Modularität (b) eine Anpassung oder Erweiterung im Falle von neuartigen anthropogenen Tätigkeiten Einzelne Teile jedes Modells können auf andere Modelle übertragen werden um andere Waldökosysteme zu evaluieren, die vergleichbarem anthropogenem Druck ausgesetzt sind.

Resumen

La presente tesis doctoral desarrolla un sistema de monitoreo y evaluación (M&E) para estimar el estado de conservación del bosque ubicado en el área de influencia del gasoducto San Miguel-Cuiabá al oeste de Bolivia. El sistema de M&E establece la base para un futuro sistema de apoyo a la toma de decisiones para alcanzar la implementación de estrategias de manejo y conservación adoptadas a las condiciones locales. El Bosque Seco Chiquitano es un ecosistema que conserva aún sus características de un bosque natural. En Diciembre del 2000 un gasoducto subterráneo entró en operaciones para exportar gas a Brasil. El gasoducto atraviesa el bosque y su impacto directo en la cobertura vegetal fue perceptible. Menos obvios son sus impactos indirectos, que están relacionados con (a): el programa de compensación ejecutado a nivel de comunidades (PDI), y (b) el uso del derecho de vía como ruta de acceso hacia nuevas áreas de bosque, especialmente para caza y extracción de madera.

Las actividades humanas más importantes que involucran el uso del suelo en el área de influencia del gasoducto San Miguel-Cuiabá son: agricultura extensiva, extracción selectiva de madera, caza y extracción de leña, y son practicadas por los habitantes de pequeñas comunidades. Estas actividades están caracterizadas por bajos niveles de tecnología, comercialización y retorno. Sí el nivel de tecnología permanece constante pero la demanda aumenta, la deforestación y la degradación del bosque se incrementarán. La combinación de aspectos del gasoducto y las características endógenas del uso del suelo forzan un programa de M&E conjunto.

El sistema de M&E se desarrolló usando una combinación de métodos convencionales y novedosos en 6 fases interactivas. Conocimiento científico y conocimiento sobre los aspectos locales del uso del suelo fueron integrados usando técnicas de ingeniería del conocimiento, lógica difusa y sistemas de información geográfica. El sistema de M&E evalúa información sobre la cobertura vegetal derivada de datos de sensores remotos y datos de uso del suelo obtenidos de levantamientos de campo y encuestas. El sistema está conformado por cuatro componentes: (a) grupo final de factores e indicadores conceptuales, (b) modelos para evaluación espacial basados en el conocimiento y el lógica difusa, (c) validación del sistema y línea de base del M&E, (d) breve protocolo de M&E.

(i) El *grupo final de factores e indicadores conceptuales* constituye un grupo relevante y validado de 17 indicadores y 11 sub-indicadores derivados de conocimiento científico y aspectos locales del uso del suelo obtenidos de levantamientos de campo y encuestas en las comunidades.

(j) Los dos modelos para evaluación espacial basados en el conocimiento y el lógica difusa, organizan los indicadores de acuerdo con sus interrelaciones y sus áreas de influencia. El modelo a escala comunal incluye todos los indicadores que tienen influencia dentro de las comunidades. El criterio de evaluación del modelo comunal es: "La presión en el bosque debida a la agricultura extensiva se mantiene dentro de límites aceptables". El modelo a meso-escala incluye los indicadores y sub-indicadores que ejercen influencia fuera de los límites de las comunidades. El criterio de evaluación del modelo a meso-escala es: "Cambios en el estado de conservación de ecosistemas como resultado del uso del suelo, es mantenido en límites aceptables".

(k) La validación del sistema y línea de base del M&E, muestra los resultados de evaluación. Información sobre la cobertura vegetal (2002) derivada de datos de sensores remotos es integrada con los datos de uso del suelo obtenidos de levantamientos de campo y encuestas (2003). Ambas fuentes de información son evaluadas por los modelos. Los resultados de línea de base muestran que a escala comunal, existe presión moderada y fuerte en el bosque alrededor de las comunidades. Esto es debido a la agricultura totalmente extensiva que se practica. A meso-escala, se observa que el área de investigación está dominada por ecosistemas naturales. 82,96 % del area total presenta muy buen estado de conservación y un 3,67 % corresponde a areas deforestadas. 11,33 % del área presenta un buen estado de conservación, mientras que 1,84 % presenta un estado moderado y solo un 0,19% muestra un nivel pobre.

(l) El breve protocolo de M&E describe los puntos más importantes a considerar a la hora de ejecutar las actividades de M&E. El proceso de M&E toma un aproximado de 5 meses de trabajo y se divide en tres fases: (a) organización general, (b) colección de datos, reporte de resultados. El personal mínimo requerido es conformado por 4 miembros: un coordinador (científico ambiental), dos consultores de campo (un agrónomo y un miembro de las comunidades) y un consultor de oficina (especialista en geo-informática). Los costos totales para Bolivia (sin considerar gastos en software) corresponden a unos 8000 Euros.

Los resultados suministran un programa estructurado para el monitoreo y la evaluación del estado de conservación del ecosistema en el área de investigación. El sistema M&E es un producto claro y lógico que considera y documenta lecciones aprendidas en el campo, y facilitan la implementación y aceptación por el usuario final (FCBC). La modularidad de los modelos permite: (a) una estimación individual del nivel de presión de cada factor, mediante la identificación de cuál actividad humana está causando mayor impacto en el ecosistema y (b) su adaptación o expansión sí (p. ej.) nuevas actividades humanas se presentan en el área de investigación. Además, partes individuales pueden transferirse a otros modelos para evaluar otros ecosistemas expuestos a presiones similares.

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"Si quieres construir un barco, no empieces por cortar las maderas y distribuir el trabajo, sino que primero has de saber evocar en los hombres el anhelo del mar libre y abierto"
Antoine de Saint Exupéry

1 Introduction

1.1 Problem statement and background

Between 1990 and 2000, 0.2% of the total vegetal cover (9 000 000 ha) was annually deforested worldwide. The regions with the highest deforestation rates were and continue to be Africa and South America with 0.8% and 0.4%, respectively. Thus, the most important processes of forest loss are still taking place in tropical regions [FAO 2001].

The Food and Agriculture Organization (FAO) [FAO 2001] defines deforestation as: (a) the long-term reduction of tree crown cover density of less than 10%, and (b) the removal of forest and its conversion into a different land use class such as shifting or permanent agriculture, ranching, mining, or water. Land use is the human activities related directly to land. Deforestation *per se* implies a land use change caused by a land cover modification through human action. Moreover, land use change can also include a change in the intensity of a previously existent land use [Müller 2003]; i.e. these are subtle changes affecting the features of the land cover but without changing its overall category [Lambin *et al.* 2003]. Utilizing the land resources or having an impact on it, a given land use determines the functioning of the land cover by interfering in its ecological processes [Mücher *et al.* 1993].

Causes of land use change have either a direct or an indirect character. Direct causes include the results of human activities that directly affect the land cover. Indirect causes are such forces that underlie the preceding causes, which operate in a diffuse manner altering one or more direct causes. Direct causes usually work at the local level, whereas indirect causes have their origin at regional, national, or even international levels, and constitute a complex system of broader factors (i.e. of the social, political, economic, demographic, technological, cultural and biophysical type). Indirect causes are often exogenous to the local agents of land use change [Kaimowitz & Angelsen 1998], [Lambin *et al.* 2003].

Petroleum operations in forest areas are involved directly and indirectly in deforestation and land use change processes [RAN & Project Underground 1998]. Besides the pollution caused in the forest by petroleum and gas activities, direct deforestation related to these activities is registered for many tropical countries such as: Gabon (rainforest and mangroves), Ecuador (rainforest), Papua New Guinea (mainly forest) [Wunder 2003], and Bolivia (mainly forest) [Ibisch 2004b]. In general, indirect impacts play a more important role in land use change [Wunder 2003].

Indirect impacts are less obvious, but alter the dynamics of local land use. They include “development” effects at the local or regional level, which are caused by local economic changes, pressures, and opportunities induced by the presence and activities of the involved companies. Indirect impacts will often be more powerful than direct impacts [Wunder 2003]. For instance, improvement of existing roads or construction of new roads makes forest areas more accessible and attractive for expansion of logging, human colonization, hunting and/or agriculture [Chomitz & Gray 1996], [Kaimowitz & Angelsen 1998], [Pfaff 1997], [Wunder 2003]. In some contexts, local populations can expect to receive economic incentives from revenue opportunities and transfers by companies. These can include: capital; incentives or access to sell agricultural products and increase of crop areas. Another aspect is the enlargement of local populations and settlements by temporary or permanent immigration due to better incomes, schools, healthcare, etc. In a comparative case study, Wunder (2003) recorded indirect negative impacts on forests in Mexico, Venezuela, Guatemala, Gabon, Nigeria, and Ecuador. The most important deforestation was shown in Ecuador, where the high rural population pressure in the highlands was combined with the improved access to forest areas provided by oil roads. The aggregation of both factors favored the emigration to forested frontiers; though regions with good market integration were preferred. In Bolivia, although to a lower degree than in Ecuador, oil and gas industry activities have catalyzed similar dynamics, which have affected forest and biodiversity [Ibisch 2004b].

Regarding oil transportation, tankers are currently the primary means of transport. Nevertheless, oil and gas transportation through pipelines is currently increasing to the point that there are more kilometers of pipelines in the world than railroads [O’Rourke and Connolly 2003]. Natural gas is rapidly gaining importance, because its combustion has a relatively low environmental impact compared with other fuels. Gas has grown from a minor fuel consumed in regionally disconnected markets, to a fuel that is transported across great distances for consumption in different economic sectors. World gas consumption is projected to double by 2030, surpassing coal as the world's number two energy source and likely overtaking oil in many industrialized countries [Mares 2004]. In the world natural gas market, Bolivia plays an important role, being ranked second in South American natural gas reserves. Since Bolivia is a landlocked country, pipelines have an essential importance as gateways for exports.

In December 2000 the underground pipeline San Miguel-Cuiabá was built in eastern Bolivia (Santa Cruz Department), to export gas to Brazil. The gas pipeline crosses the Chiquitano Dry Forest that is an endemic ecoregion[1] of Bolivia. This ecoregion is one of the most diverse in plant species within the dry forests of the world [Ibisch 2004a]. Up to the present, at least 237 tree species have been found and, in a section of 400 ha of forest, more than 500 plant species were found [Jardim *et al.* 2003]. The viability of biodiversity is determined by the status of conservation of an ecosystem. [Ibisch, 2002a] estimated that most areas of the Chiquitano Dry Forest (total area 101,769 Km^2) currently show a good to very good status of conservation; it is still an ecosystem close to natural conditions.

Nevertheless, two factors represent threats for the Chiquitano Dry Forest: First, there is an increasing trend in deforestation in the Santa Cruz Department. Between 1993 and 2000 the total forest cover of the Department decreased by 1,424,033 ha (thereof 432,991 ha of Chiquitano dry forest), due to both established agriculture and shifting cultivation [Camacho *et al.* 2001]. Second, there is evidence of indirect deforestation associated with other gas pipelines in the country. In 1972 a gas pipeline was built to Argentina which crosses the Chaco Forest from the north to the south. Nowadays, the right of way is an established pathway with abundant ranches found on both sides. Similarly, only after five years of construction, the right of way of the gas pipeline Río Grande - São Paulo - Porto Alegre (Brazil) is used as pathway for livestock, logging, and expansion of agricultural lands [Ibisch, 2004b]. Analogous effects can be expected in the area of influence of the gas-pipeline San Miguel-Cuiabá, which in the long term, would generate forest degradation and deforestation. The building of the gas-pipeline San Miguel-Cuiabá generated much controversy among

[1] See section 1.3.2.2.

several stakeholders, whose concern originated in the agreement to create the Foundation for the Conservation of the Chiquitano Dry Forest (FCBC), a program for the conservation of this important forest.

Because of the vulnerability of the influence area of the gas-pipeline and towards an early identification of subtle ecosystem changes, the FCBC has to implement a monitoring and evaluation (M&E) system as core element for decision-support. Based on [IFAD 2005] and in accordance with the aims of this research, M&E activities are defined as the regular collection and analysis of information to assist timely decision making. It is a continuing function that uses methodical collection of data to provide management with early indications of the conservation status of the ecosystem. In specifying an M&E plan, science is needed to identify indicators and measures of the values of interest, as well as developing reference conditions [Reynolds 2003a]. Scientists have a key role by making progress in the implementation of criteria and indicators, by synthesizing and integrating technical as well as quantitative and qualitative information [Raison *et al.* 2001]. There is an imperative need for monitoring arrangements that deliver compressive, relevant, scientifically sound and cost-effective information [Prabhu *et al.* 2001]. The main weaknesses in the assessment of land use changes in the Bolivian low lands are the lack of local studies adapted to the different agro-ecological areas, as well as systematic and continuous monitoring [Pacheco 1998]. Changes of land cover assessed with satellite imagery may not necessarily coincide with actual changes in land use [FAO, 2001]. Especially in tropical ecosystems that are close to natural conditions, subtle changes in land use are difficult to recognize. Land cover information improved with land use data, provides more reliable information of land use, which can be used as proxy of the ecosystem's conservation status. Scientific knowledge and local issues of land use are integrated in this dissertation, by using knowledge engineering techniques, fuzzy logic, and GIS. Land cover information derived from remote sensing data is improved with data from village-level surveys, constituting an operational M&E system. The fuzzy logic knowledge-based M&E system assesses the conservation status of the forest, in the influence area of the gas-pipeline San Miguel-Cuiabá, and sets up the basis for a prospective decision-support system.

1.1.1 Objectives

In order to support the protection of the biodiversity and the ecological integrity of the Chiquitano Dry Forest, and to give an early warning about environmental impacts from local land use and from the gas-pipeline San Miguel-Cuiabá, the research project has the following main objective:

To develop a suitable M&E tool towards assessing the conservation status of the forest in the influence area of the gas-pipeline.

Following are the specific objectives of the project:

- To acquire and systematize knowledge concerning the characteristics of local land use in the influence area of the gas-pipeline San Miguel-Cuiabá.
- To acquire and systematize knowledge concerning the indirect impacts associated with the gas-pipeline San Miguel-Cuiabá on the Chiquitano Dry Forest.
- To identify and develop key indicators that enable a systematic supervision over time.
- To provide managers and interested stakeholders with a cost and time effective M&E scheme for large[2] area ecosystems.
- To set up the basis for a prospective decision support system that assists decision makers in the formulation of locally adapted resource management strategies.

1.2 Bolivia and its natural gas sector

1.2.1 The country: a brief overview

Bolivia is located in west-central South America between parallels 9° 39’ and 22° 53’ of latitude south and 57° 25’ and 69° 38’ of longitude west. Landlocked, the country shares borders on the north and east with Brazil, in the southeast with Paraguay, in the south with Argentina, with Chile in the southwest, and with Peru in the west (Fig. 3). The total area encompasses 1,098,581 km^2. Official languages are Spanish (main language and most widely used), as well as Aymara and Quechua. Aymara and Quechua are used mainly by the more populous indigenous cultures on the Andean plateau and central valleys. At least other 10 linguistic groups are also spoken in different regions of the country [Montes de Oca 1997].

[2] Circa 300,000ha.

Bolivia was founded as an independent nation in 1825. The government form is a republic with three branches: Legislative, Executive, and Judicial. The main political division of the country is made up of nine departments (La Paz, Pando, Beni, Santa Cruz, Tarija, Chuquisaca, Potosi, Cochabamba and Oruro). The official capital is Sucre (seat of the Judicial branch) but the *de-facto* and better-known capital is La Paz (seat of the Executive & Legislative branches) [Montes de Oca 1997].

In the year 2001, the country's total population was 8,274,325 inhabitants [Instituto Nacional de Estadística 2004] (49.95% belongs to the indigenous cultures [Instituto Nacional de Estadística 2003]). 65.43% of the total population lives in urban areas and 37.56% in rural areas [Instituto Nacional de Estadística 2004]. Together with the suburb of El Alto (647,350 habitants), La Paz (789,585 habitants) is the country's largest city (1,436,935 habitants); followed by Santa Cruz (1,113,582 habitants) and Cochabamba (516,683 habitants) [Instituto Nacional de Estadística 2001].

The Gross Domestic Product (GDP) *per capita* is $US 2,355, which situates Bolivia as one of the poorest countries in Latin America (GDP *per capita* $US 6,880). The life expectancy is 62 years and the rate of literacy 85% [PNUD 2002]. Whereas wealthy city elites, who are mostly of Spanish ancestry, have traditionally dominated political and economic lives, the majority of Bolivians are low-income subsistence farmers, miners, small traders, or artisans. Bolivia is the world's largest producer of tin. The country has the second-largest reserves of natural gas in South America, but there is a great deal of sensitivity and conflict over the exploitation and the export of the resource, especially among Indigenous groups.

1.2.2 The natural gas sector

The oil production in Bolivia started in 1927 with the operation of the first oil well (Bermejo - Department of Tarija) by the Standard Oil of Bolivia, a North American Company. In December 1936 the State-owned oil company Yacimientos Petrolíferos Fiscales Bolivianos (YFPB) was founded, which in March 1937 expropriated and transferred the rights of the North American Company to the Bolivian state. In the 1940s and 1950s, joint ventures were allowed[3], as well as the first oil pipelines (Camiri - Cochabamba and Lamboyo - Sucre) were

[3] Most important companies were: Bolivian Gulf Oil Co., Shell Prospecting Co., Bolivia - California Petroleum Co., Texas Co.

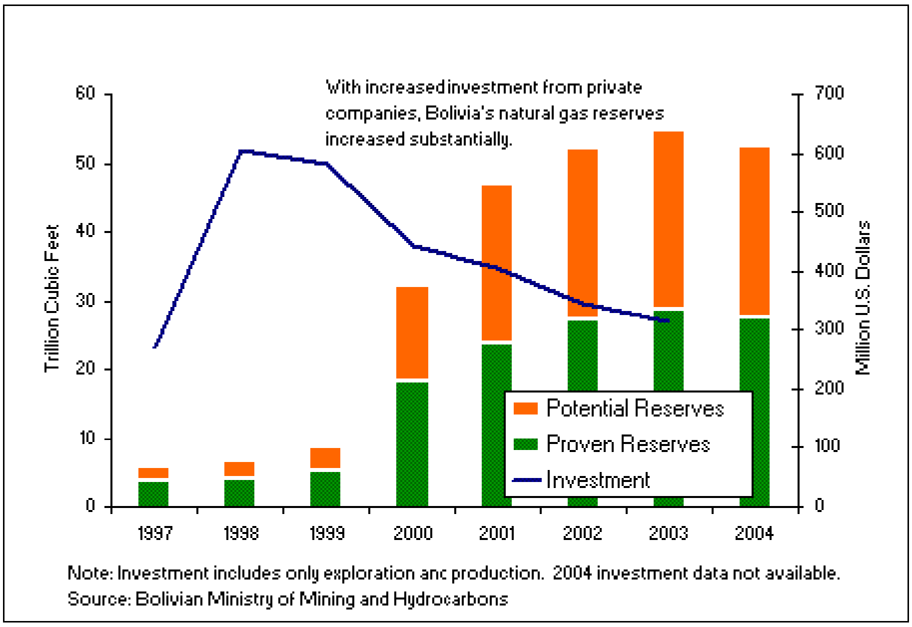
built. The natural gas production began to play a role in both the economy and politics in the 1960s; the first contract for gas exportation to Argentina was signed in 1968 [Correa 2003]. This contract provided the legal framework for the building, in 1972, of the first international gas pipeline in the Southern Cone (Argentina, Bolivia, Brazil, Chile, Paraguay and Uruguay), linking Bolivia and Argentina [Mares 2004].

The capitalization, i.e. the privatization of Bolivia's hydrocarbon sector started in 1994, with the enforcement of the Capitalization Law[4] that was followed by a new Hydrocarbons Law[5] in 1996. YPFB was divided into two upstream units, a transport company, a refining company, and various service companies. The government founded the Superintendence of Hydrocarbons to regulate the oil and gas industries. At the same time as YPFB became the administrator of international negotiations and contracts with foreign oil companies [Esser 2004].

Until 1996 the natural gas certified reserves amounted to circa 6 trillion cubic feet (Tcf) [Andersen & Faris 2002]. Following the privatization of the hydrocarbon sector, the known natural gas reserves increased exponentially, due to exploration activities financed through investment from some of the world's largest energy companies. According to governmental data, current[6] proven natural gas reserves are 27.6 Tcf, total (proven and potential) reserves amount to 53.3 Tcf. In a short period of time, Bolivia appeared abruptly in the world natural gas market, ranking second after Venezuela in South American natural gas reserves (Fig. 1) [Esser 2004].

[4] Capitalization Law N° 1544.
[5] Hydrocarbons Law N° 1689.
[6] January 2004.

Figure 1. Evolution of Bolivia's natural gas reserves between 1997 and 2004



Source: Esser 2004

Notwithstanding its large reverses, Bolivia has been slow the development of its natural gas sector, which is currently focused on exports (in the year 2001 Bolivia traded 0.2 and 2.6 billion cubic meters to Argentina and Brazil, respectively [Mares 2004]). The domestic natural gas market is small but growing in importance. In 1990, natural gas accounted for only 3% of the country's total primary energy, but by 2002, its share was 25%. The government is at present supporting the building of two gas-to-liquid plants, the installation of 230,000 natural gas connections for residential use by 2007, and the adaptation of 80,000 vehicles to use natural gas [Esser 2004]. The residential use of natural gas is dominant in urban areas.

1.2.2.1 Infrastructure for transport of natural gas: pipeline network

The domestic natural gas pipeline network has a total length of 3,720 km [Dirección de Transporte de Hidrocarburos por Ductos 2000], and can be divided into northern and southern systems (Fig. 2). The northern domestic system supplies the cities of La Paz, Cochabamba, Oruro, and Santa Cruz. The southern system begins in the town of Yacuiba on the Argentine border, and has two branches, one supplying the cities of Sucre and Potosí and the other Tarija in the south [Esser 2004].

Figure 2. Map of domestic natural gas pipeline network

Source: Dirección de Transporte de Hidrocarburos por Ductos 2000

The domestic natural gas pipeline network connects the Southern Cone network (see Fig. 3). The southern domestic system extends to Argentina, where the consortium Argentina Pluspetrol exports gas from its Bolivian fields in Bermejo and Madrejones [Esser 2004]. This gas pipeline was Bolivia's only cross-border interconnection until July 1999, when natural gas began flowing through the Bolivia-Brazil pipeline (Río Grande - São Paulo - Porto Alegre) [Correa 2003], which is connected to the northern domestic system.

With a length of circa 3,200 km, the Bolivia-Brazil pipeline is the longest in South America, and has a maximum transporting capacity of up to 1 billion cubic feet (Bcf.) of gas per day. The first section of the pipeline was finished in December 1998, connecting Río Grande, Bolivia to São Paulo, Brazil. The second section, extending southward from São Paulo to Porto Alegre, was finished in April 2000 [Esser 2004]. A second Bolivia-Brazil pipeline (Río San Miguel - San Matías - Cuiabá) began operations in May 1, 2002 [GasOriente Boliviano 2003].

Figure 3. Map of cross-border gas pipelines in South America (2002)

Source: IEA 2002

1.2.2.1.1 The San Miguel - Cuiabá gas pipeline

The gas pipeline has a total length of 633km, a diameter of 18“ and a capacity of 2.5 million cubic meters per day [GasOcidente 2003]. The project is an essential part of the *Cuiabá Integrated Energy Project* and was jointly developed by ENRON International, SHELL Gas

Latin America B.V. and TRANSREDES S.A. [Céspedes *et al.* 2002]. The project had support from the Bolivian, Brazilian, and Argentinean governments, which regard the project as "a model for the economic integration of MERCOSUR" [GasOcidente 2003]. This gas pipeline starts in Río San Miguel, Bolivia, where it connects to the main Bolivia-Brazil pipeline (red and blue lines respectively in Fig. 4). The pipeline crosses through San Matías and extends to Cuiabá, Brazil, where the line fuels a 480-MW thermal power plant [Esser 2004].

Two companies operate the San Miguel - Cuiabá pipeline. The first company, GasOriente Boliviano Ltda. (GOB) of Bolivia (founded by ENRON and SHELL) is the owner of the Bolivian pipeline segment (Río San Miguel – San Matías). The second company GasOcidente do Mato Grosso Ltda. (GOM) of Brazil is the owner of the Brazilian pipeline segment (San Matías – Cuiabá). A third company (EPE) operates the "Mario Cova" Thermoelectric Power Plant which supplies the city of Cuiabá with electricity [Massinon & Sugrañes, 2003]. The San Miguel - Cuiabá gas pipeline has great relevance at different levels: At international and national level it generates economic benefits for the involved gas companies, insuring a market for part of the gas production of Bolivia and Argentina, and serving for Brazil as source of energy with positive implications for its regional development.

Figure 4. Bolivian pipelines that export gas to Brazil

Source: GasOcidente 2003

1.2.3 The Chiquitano Forest Conservation Foundation

Cross-border gas pipelines in Bolivia are associated to important events in the country's life. The first gas exportation contract with Argentina in 1968 influenced the nationalization of hydrocarbons (see Correa, 2003). In September 2003, a popular revolt broke out in response to the government's plan to export liquefied natural gas (LNG) to the United States and Mexico via Chile. This political problem had its roots in the Pacific War (1879-84) in which Bolivia lost 120,000 km² of its territory and its coast on the Pacific Ocean to Chile. As a result, a series of conflicts broke out which forced former president Gonzalo Sanchez de Lozada out of power [Esser 2004]. These conflicts have not been resolved yet and Sanchez de Lozada's successor, Carlos Mesa, tendered his resignation in March 2005. Mesa's resignation was an effort to pacify demonstrators, who were demanding that international energy companies pay higher tariffs to exploit natural gas reserves. The term in office of Mesa had been dogged by conflicting demands from the business sector, indigenous movements, and gas-rich provinces seeking autonomy [News 2005].

The San Miguel - Cuiabá gas pipeline originated also an important event, this time with a positive outcome. Controversy concerning the suitable route for the gas pipeline took place between the government, gas companies, nature protection institutions, and indigenous organizations. In spite of the controversy, the pipeline was built crossing the Chiquitano Dry Forest. As a consequence, the ecological significance and threat of the forest was highlighted in the discussions. Finally as a result of the negotiations between conservation organizations[7] and the owner companies[8] of the gas pipeline, the parts agreed to create a program for the conservation of the Chiquitano Dry Forest, which is managed under a voluntary fund and foundation whose main aim is the long-term conservation of the ecosystem.

The common goal was to find solutions to the problems that threaten the region due to major infrastructure projects and the use of natural resources. The Chiquitano Forest Conservation Foundation (FCBC from the Spanish initials) was created in 1999 as a private, non-profit organization, with its own resources and stable funding mechanisms. The FCBC has the mission of supporting projects that contribute to the biodiversity protection and the

[7] Fundación Amigos de la Naturaleza (FAN - Bolivia), Fundación Amigos del Museo de Historia Natural Noel Kempff Mercado, Missouri Botanical Garden (MBG), Wildlife Conservation Society (WCS).
[8] ENRON and SHELL

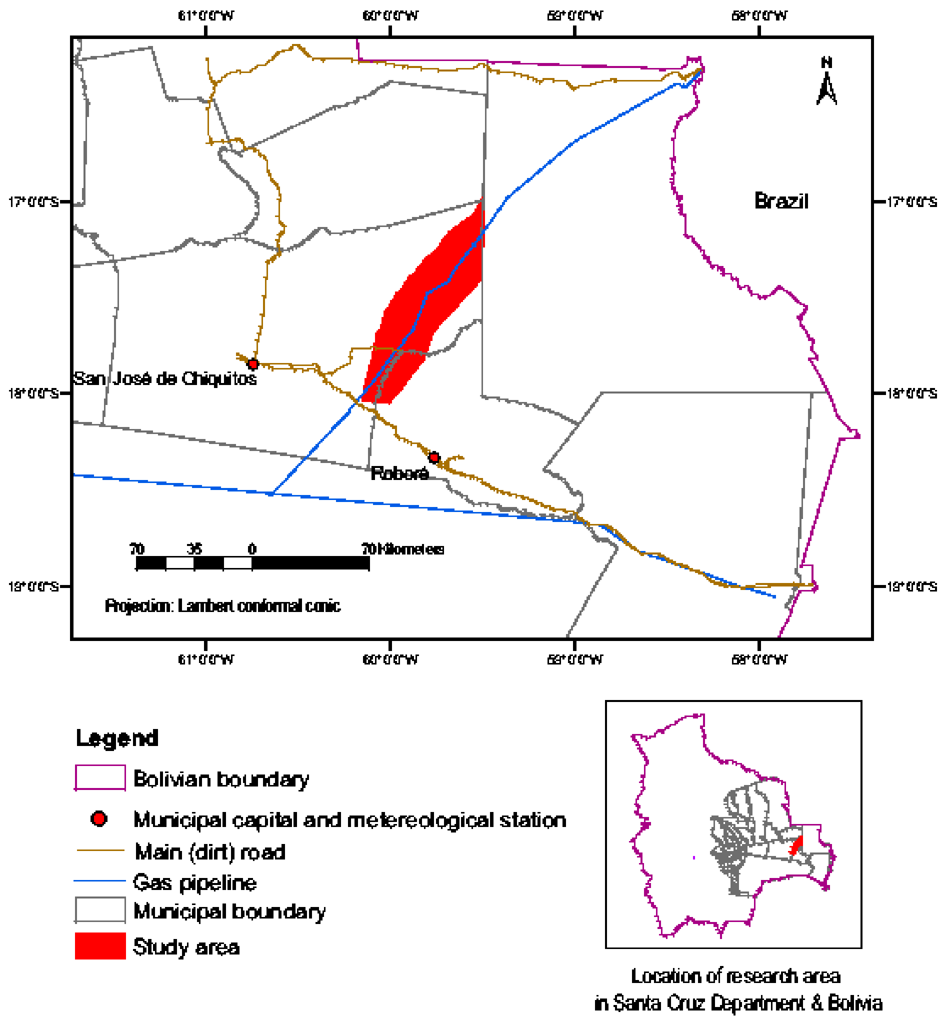
sustainable development of the Chiquitano Dry Forest and its surroundings, the Cerrado and Bolivian Pantanal ecoregions [FCBC 2003].

1.3 The research area

1.3.1 Location

The research area is located in the lowlands of Bolivia, between 60°8’40”W and 18°0’49”S in the north, and 59°30’24”W and 17°0’17”S in the south (in geographic latitude and longitude), on both sides of the gas pipeline that crosses the Chiquitano Dry Forest. The research area belongs politically to the municipalities of San José de Chiquitos and Roboré in the Department of Santa Cruz (Fig. 5).

Figure 5. Research area location



Source: (a) Area: Author. (b) Rest of data: adopted from [Céspedes *et al.* 2002]

1.3.2 Natural Conditions

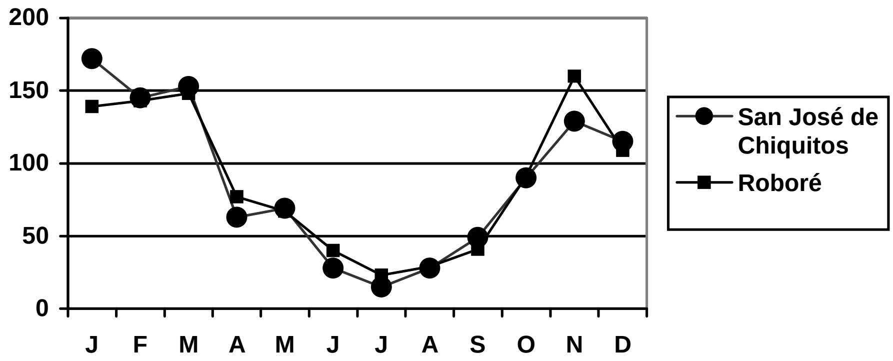
1.3.2.1 Abiotic factors

1.3.2.1.1 Climate

According to [Villapando *et al.* 2002] and [Ibisch *et al.* 2002a] the climate is of the hot, tropical sub-humid type. Two well-defined periods characterize the climate in the region: (a) a rainy season from November to March that coincides with the southern summer, with higher temperatures between September and March and (b) A dry season from May to September, which matches the southern autumn and winter (see Figs. 6 and 7).

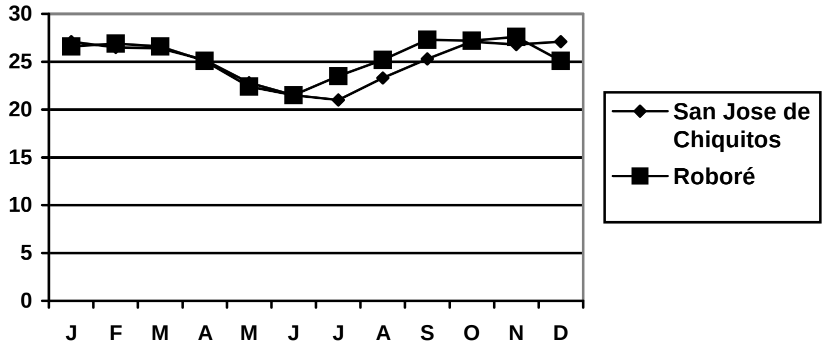
The relative humidity has the same pattern as the rainfall, with highs in March and lows in September. The winds come mostly from the North to Northwest.

Figure 6. Monthly average precipitation[9]



Source: Villapando *et al.* 2002

Figure 7. Monthly average temperature[9]



Source: Villapando *et al.* 2002

There are no meteorological stations within the research area. The nearest stations are in San José de Chiquitos and Roboré (see Fig. 6). The average precipitation reaches 1,057 and 1,066 mm/year respectively[9]. The annual total precipitation presents strong variation between years (see Villapando *et al.* 2002), therefore is not possible to define a pattern for the annual precipitation. San José de Chiquitos reached its minimum in 1993 (563.6 mm) and maximum in 1992 (1,486.3 mm), and in Roboré the minimum was in 1999 (651.7 mm) and maximum in 1992 (1,484.1 mm). Contrary to the precipitation, the temperature variations between years remain relatively stable (see Villapando *et al*. 2002). The average temperature is 25 °C in both stations. Minimum and maximum average temperatures are 18 °C and 31 °C, respectively.

1.3.2.1.2 Topography, physical geography, geology, and soils

The relief in the research area is predominantly flat with the presence of some soft hills and plateaus (Map (a) of Fig. 8), which respectively belong to (a) the Brazilian Shield and (b) the Chaco Palaeozoic plains. These are the main geomorphologic units present in the area (see Map (b) of Fig. 8).

(a) The Brazilian shield dominates the area; it is composed principally of igneous and metamorphic rocks belonging to the Precambrian (Craton de Paraguá with an estimated age of 1,400 to 1,280 billion years) and is associated to some sedimentary rocks of the Cambrian. Soils have a sandy-skeletal texture and low fertility; they are of the inceptisol, ultisol, alfisol, and oxisol types and present high susceptibility to erosion caused by water.

(b) The Chaco Palaeozoic plains constitute a high plateau, made up of a series of micro-plications. These micro-plications were highly eroded in the Devonian period. Afterwards they were covered successively with sediments of the Tertiary and Quaternary. The soils types are oxisol, alfisol, inceptisol and entisol, those textures vary from sandy to silty. They have low fertility and susceptibility to erosion caused by wind [Wachholtz 2002].

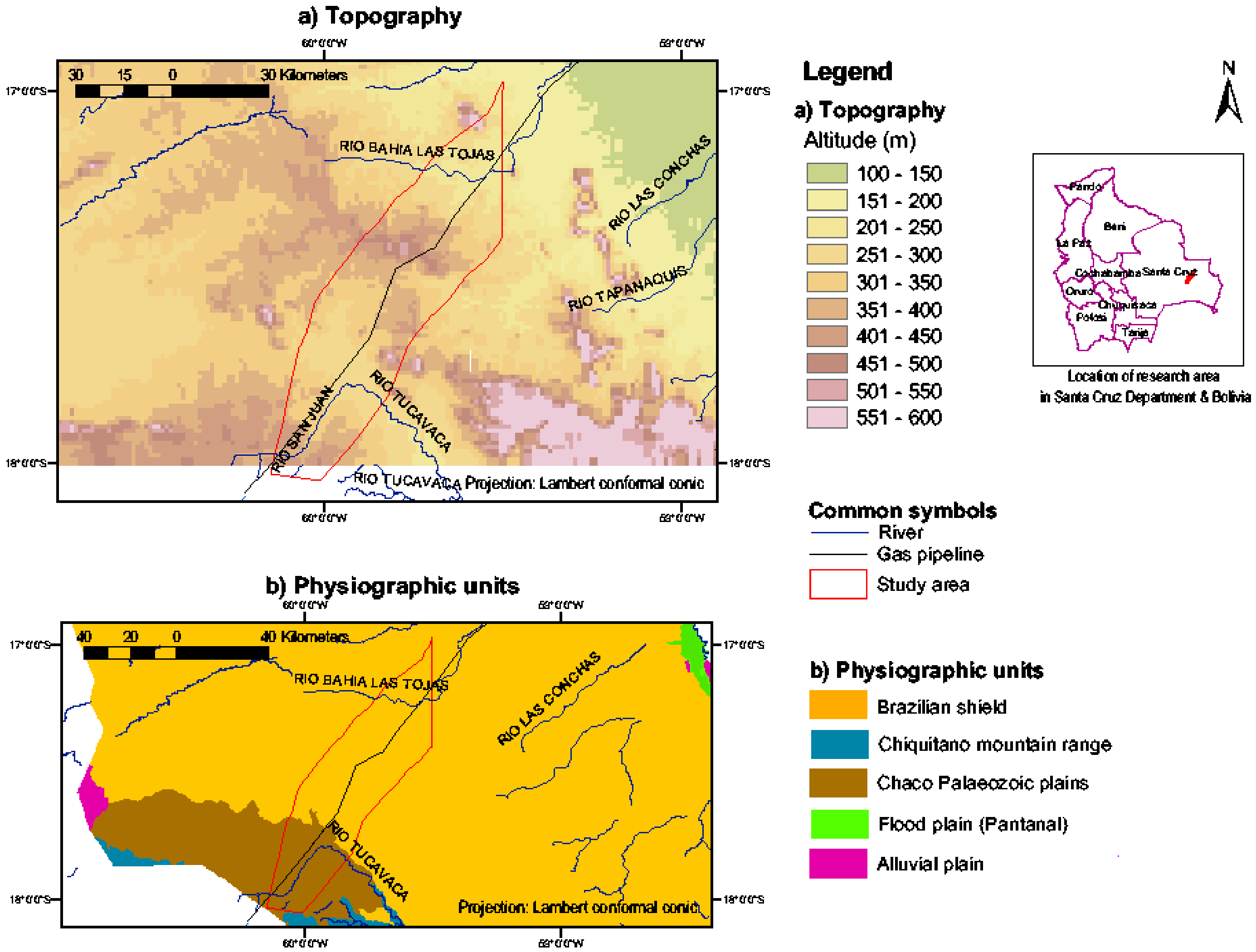
Concerning the suitability of soil for human use, the research area is characterized by soils with critical limitations for farming. They have none or thin topsoil and nutrient poor subsoil

[9] Period from 1986 to 2000.

with a high clay content. According to the agro-ecological soils classification from the U.S. Department of Agriculture, which recommends (based on its physical and chemical characteristics) the use for each soil type; in the research area the main soils classes are catalogued as Class VI and VII[10]. Both classes present critical limitations for farming caused either by drainage, erosion, or fertility. These soils are most suitable for forest or, to a lesser extent, for pastures (for details, see Wachholtz 2002).

[10] Assessment scale: Class I (few limitations) to VIII (most limitations).

Figure 8. Topography, hydrography, and physiography of the research area



Source: Map (a) USGS 2004 and Map (b) Adopted from Cordecruz y Cooperación Técnica Alemana 1995

1.3.2.1.3 Hydrography

The research area belongs to the Plata River watershed, which is shared by four bordering countries: Brazil, Argentina, Paraguay, and Uruguay. There are two main water streams within the area: (a) the Tucavaca river in the south, which belongs to the Tucavava-Otuquis River sub-watershed, and (b) the Bahia Las Tojas stream in the north, which pertains to the Curiche Grande River sub-watershed (Fig. 8).

(a) The Tucavaca River is the only permanent stream in the area. The principal tributaries of this sub-watershed are the Aguas Calientes, San Rafael, Los Tocos, La Canoa Rivers, and other smaller rivers. It is formed by a water system which begins in the Sunsás, Santiago and Chochís mountain ranges, forming a valley through which flows the Tucavaca River, fed by a series of streams (Los Arcos, Canoa, La Cal) and brooks, which end in the Bañados (swamps) de Otuquis.

(b) The Curiche Grande River sub-watershed is formed by a series of streams (Las Señoritas and Tuná, among others), that begin in the Sunsás, Santiago, Bella Boca and Santo Corazón mountain ranges; brooks (Aguas Calientes, Taperas, etc.); rivers (Santo Corazón, San Fernando, Correreca, Mercedes, Tuná, Magueses, etc.), that flow towards the Curiche Grande River, which is the main river in the area. In this watershed there is also a complex system of small lakes, pools, (Mandioré, Gaiba, Uberaba, Mirim, Vista Hermosa), swamps (Caribe, Vista Hermosa, and Curiche Tapera) and large flood zones [Justiniano and Reichle 2002].

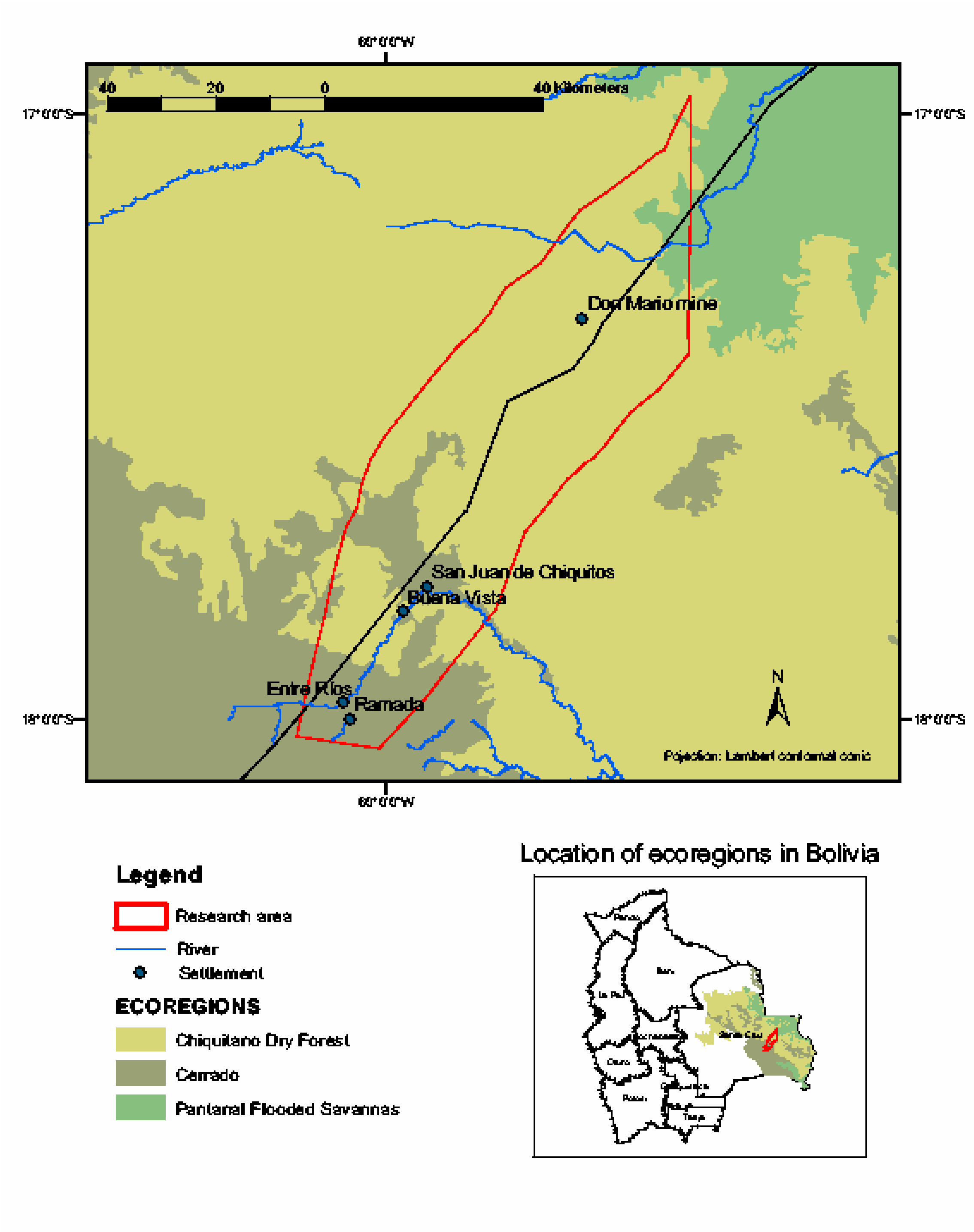
1.3.2.2 Biotic factors

1.3.2.2.1 Ecoregions and biodiversity

Because of its holistic approach the use of ecoregions to classify natural areas is useful for conservation aims; especially for countries that have large extents of undisturbed and poorly investigated natural areas. This approach defines an ecoregion as an area, which consists of a grouping of natural communities that: (a) share many taxa, ecological dynamics and environmental conditions; (b) have greater biological and ecological interdependences within themselves than with communities outside the area; and (c) show common patterns for production of biomass, including forestry and agriculture [Ibisch 2004a].

Although the current knowledge about the Bolivian natural areas is poor, the country is situated among the 15 richest nations in species worldwide. 3 of the 12 Bolivian ecoregions are found in the research area: (a) the Chiquitano Dry Forest, (b) the Cerrado, and (c) the Pantanal Flooded Savannas (Fig. 9) [Ibisch 2004a], [Ibisch & Reichle 2002].

Figure 9. Ecoregions identified in the research area



Source: Adopted from Ibisch & Reichle 2002

(a) Most of the research area is dominated by the Chiquitano Dry Forest ecoregion, which is located between the humid climate of the Amazon and the dry climate of the Chaco. The geology is dominated by the Precambrian Shield (Brazilian Shield). The predominant vegetation is deciduous to semi-deciduous forest, moderately high (15-20/25 m). Most important vegetal families are: Fabaceae (34 species), Bignoniaceae (27 species), Mimosaceae (17 species), Caesalpiniaceae (15 species), Euphorbiaceae (14 species), Acanthaceae (12 species), Poaceae (11 species), and Rubiaceae (10 species). The ecoregion is constituted by eight vegetation units, and in the research area four of them are found: Lowland Chiquitano Dry forest, Transition Chiquitano Dry forest-Chaco, Elevated Chiquitano Dry Forest, Riverine Chiquitano Forest.

- Lowland Chiquitano Dry Forest: 50% of trees are deciduous; generally grow in soils characterized by moderate fertility and low profundity. The canopy reaches the 20m in height, some trees even 30m and is quite closed so that light almost can not penetrates. The undergrowth reaches 8 to 14m in height. Stoloniferous caespitose plants, succulent plants, ferns, and grasses dominate the herbaceous layer. At least 186 plants species are found.
- Transition Chaco to Chiquitano Dry Forest: located in valleys with low slope, on clay-silt soils with fine texture and moderately badly drained and occasionally stagnant. The canopy is more or less discontinuously structured and trees are between 15-20m high. The undergrowth reaches 8 to 10m in height. Stoloniferous caespitose plants and grasses dominate the herbaceous layer. At least 40 plants species are found.
- Elevated Chiquitano Dry Forest: forest with the same proportion of deciduous and non-deciduous trees. This vegetation unit is distributed in hills and in some mountainous areas of the Pantanal, on moderately deep and well-drained soils. The canopy reaches 25m in height and some trees up to 35 m. The undergrowth reaches 6 to 8m in height. The herbaceous layer is poor represented by some terrestrial bromeliads, stoloniferous caespitose grasses and ferns. At least 59 plants species are found.
- Riverine Chiquitano Forest: in the Chiquitano peneplain is well represented, especially in topographic depressions of valleys. The Riverine Chiquitano Forest generally grows in relatively young soils of dark grey color and clayey texture with bad drainage, which are flooded temporarily by river water. The canopy is

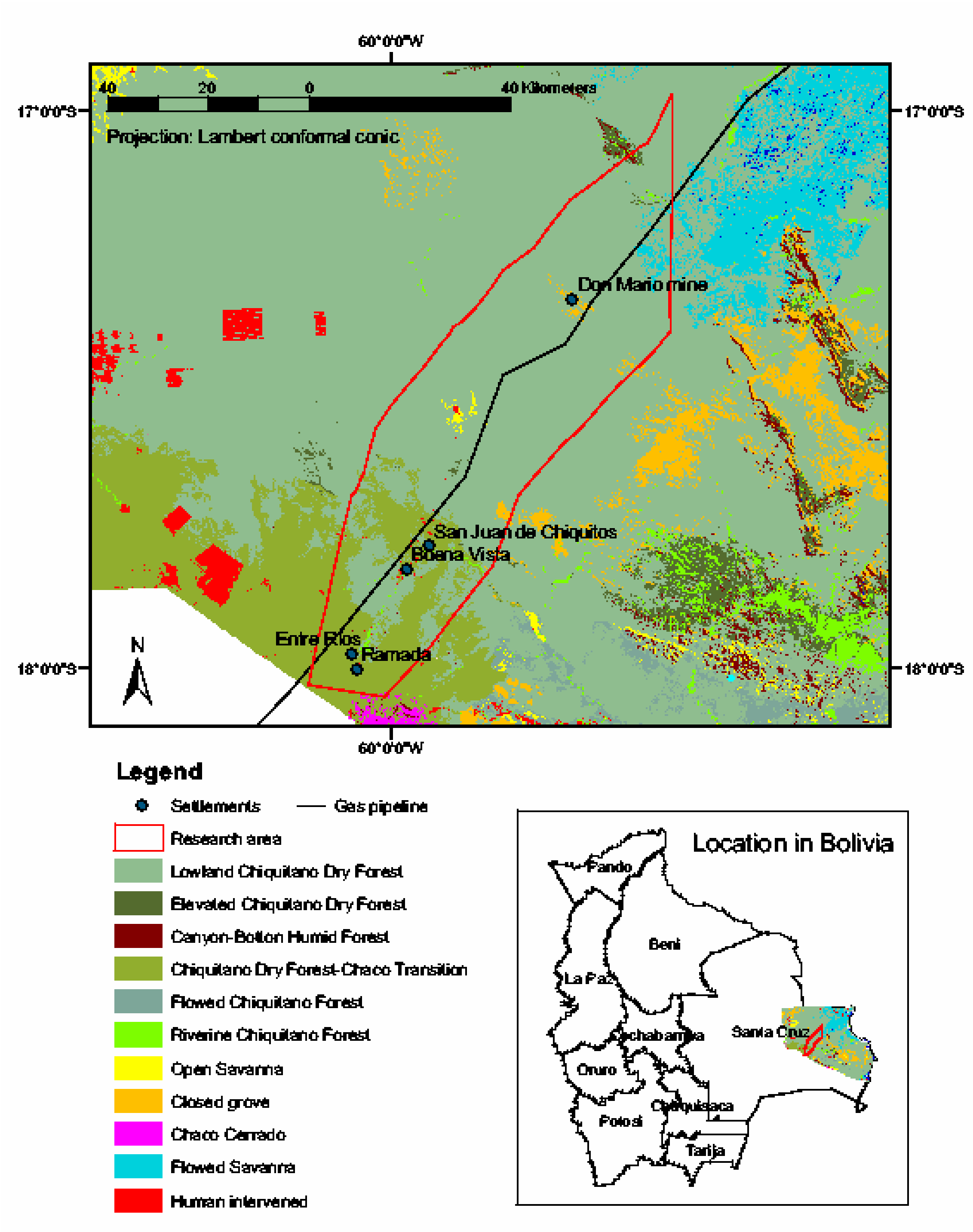
composed of trees with a maximum height of 15m and has a discontinuous structure, which in some areas the light penetrates to the undergrowth. Emergent trees are isolated and have a maximum height of 25m. The arboreal undergrowth is not very uniform and is conformed by trees of 5 to 10m. The shrubby undergrowth is very dense. Latifoliate herbs and grasses dominate the herbaceous layer. Lianas are abundant and are concentrated on the tree tops, constituting a thicket between the arboreal undergrowth and herbaceous layer. At least 120 plants species are found.

(b) The Cerrado has a "mosaic" distribution, which intermingles between the Chiquitano Dry Forest and Pantanal Flooded Savannas. The climate is semi-humid. The vegetation is composed of a lower grassy covering and small bushes, with small twisted trees scattered throughout. These trees are resistant to the fires in the dry season because of their thick, rough bark. The soils of this ecoregion are generally shallow, stony, and infertile. The most important plant families are: Poaceae (47 species), Fabaceae (15 species), Vochysiaceae (12 species), Asteraceae (10 species), Caesalpiniaceae y Rubiaceae (9 species). The ecoregion is constituted by seven vegetation units, and in the research area two of them are found: Close Grove and Open Savanna.

- Close Grove: Vegetation widely distributed in the Chiquitano hills, in the Chiquitano peneplain and hills of the Pantanal, on very stony soils with low profundity or on old and very poor soils. Trees and shrubs dominate the vegetation cover. The canopy is dense from 6 to 10m of height. Emergent trees are abundant and reach up to 18m in height. The shrub undergrowth is 1 to 3m high. The herbaceous layer is small and lianas are uncommon. At least 97 plants species are found.
- Open Savanna: This vegetation unit is generally distributed in the Chiquitano and Pantanal hills, grows in soils with gravel and low profundity. Grasses dominate the vegetation cover; some shrubs of 1.5m of height are found. At least 49 plants species are found.

(c) The Pantanal Flooded Savannas are low plains, which are seasonally flooded by water from rain and rivers overflowing into the zone. Depth and duration of the overflow, erosion, sedimentation and chemistry of water determine the vegetation. The predominant vegetation is savannas, marsh, aquatic plants, and flooded forest. Alluvial soils dominated the plain. This ecoregion is almost non-existent in the research area. At least 71 plants species are found.

Figure 10. Vegetation units

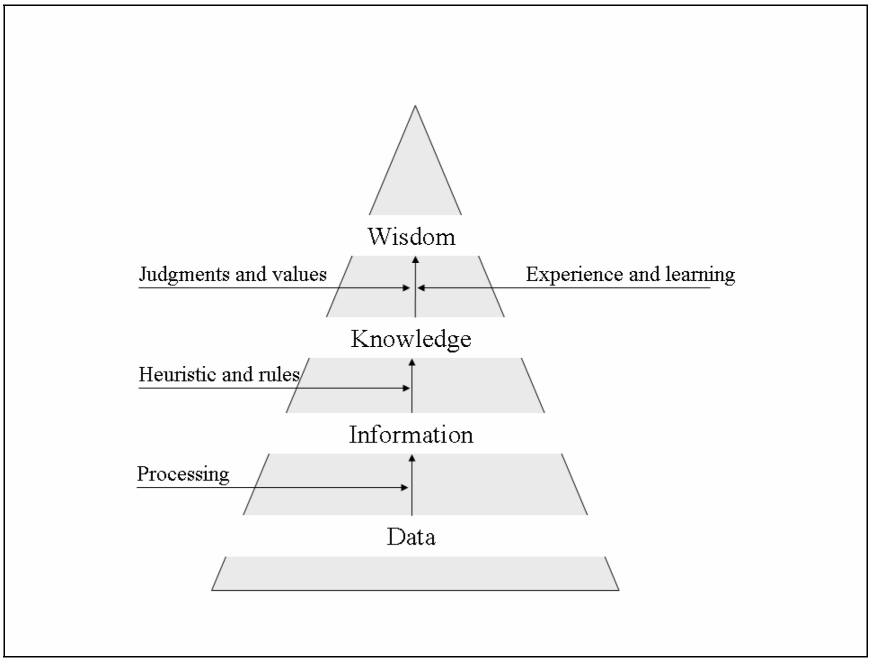


Source: Adopted from Guillén *et al.* 2002

1.4 Brief outline of knowledge-based models and fuzzy logic[11]: towards operational systems

Knowledge engineering refers to the activity of extracting and explicating the knowledge of domain experts; knowledge engineering is concerned with the representation of knowledge [Evermann 2005]. Knowledge representation is a systematic way of encoding the available knowledge about some domain or subject area. It deals with the organization, codifying, and storing of information, in order that its attributed meaning is clear [Schmodlt & Rauscher 1996]. Information is a collection of data with at least some level of organization and processing, which is only converted into knowledge when a justified belief in its truth value is developed by means of heuristics and rules [Partridge & Hussain 1995], [Schmodlt & Rauscher 1996]. Knowledge is a set of assertions and their relationships accumulated over a long period of time, which can be used to reason about the world and to solve problems [CIFOR 1999], [Schmodlt & Rauscher 1996]. Wisdom is obtained through the judgment and value system of the responsible(s) for problem solving and decision making. Wisdom belongs to a higher level that in most cases is not achieved, but it could well be an objective aimed at knowledge-based models [Partridge & Hussain 1995] (see Fig. 11).

Figure 11. Hierarchy of data, information, and knowledge structure



Source: [Partridge & Hussain 1995]

[11] For detailed discussion, see [Partridge & Hussain 1995], [Reynolds 2001], [Reynolds et al. 2003], [Rodriguez-Bachiller & Glasson 2004] and [Schmodlt & Rauscher 1996].

Regarding ecosystems, the representation of what we think we know about them is often a problematical task. Scientific frameworks are valuable structuring tools, but a fundamental difficulty is that there are *per se* ill-defined frameworks. The knowledge about ecosystems and the human forces affecting them is incomplete. Conceptual models are frequently not well defined, because the underlying arrangement or syntax of the problem specification is imprecise in the best case and poorly articulated in the worst. The development of logic models (also known as knowledge bases or knowledge-based models) is one approach to deal with the lack of specificity of problems [Reynolds 2003].

Knowledge based reasoning is a general modeling methodology in which phenomena or problems are described in terms of conceptual entities and their logical inter-relationships. This type of modeling is particularly proper when: (a) the problem entities or their inter-relationships are intrinsically abstract in a way that mathematical models of the problem are difficult or even not possible to formulate, i.e. the problem is easier to solve with logic; or (b) when a mathematical solution may be possible, but current knowledge is too vague to formulate an accurate mathematical model. Concerning ecosystems, several institutions and universities have developed numerous mathematical models to describe some of the important (from almost infinite) relations of interest to ecosystem management. Nevertheless, many relations have not been studied within enough profundity to provide more suitable general mathematical models. Moreover, there is often a wealth of human experience in these institutions that can be drawn upon to develop useful knowledge based models to guide decision making [Reynolds 2001].

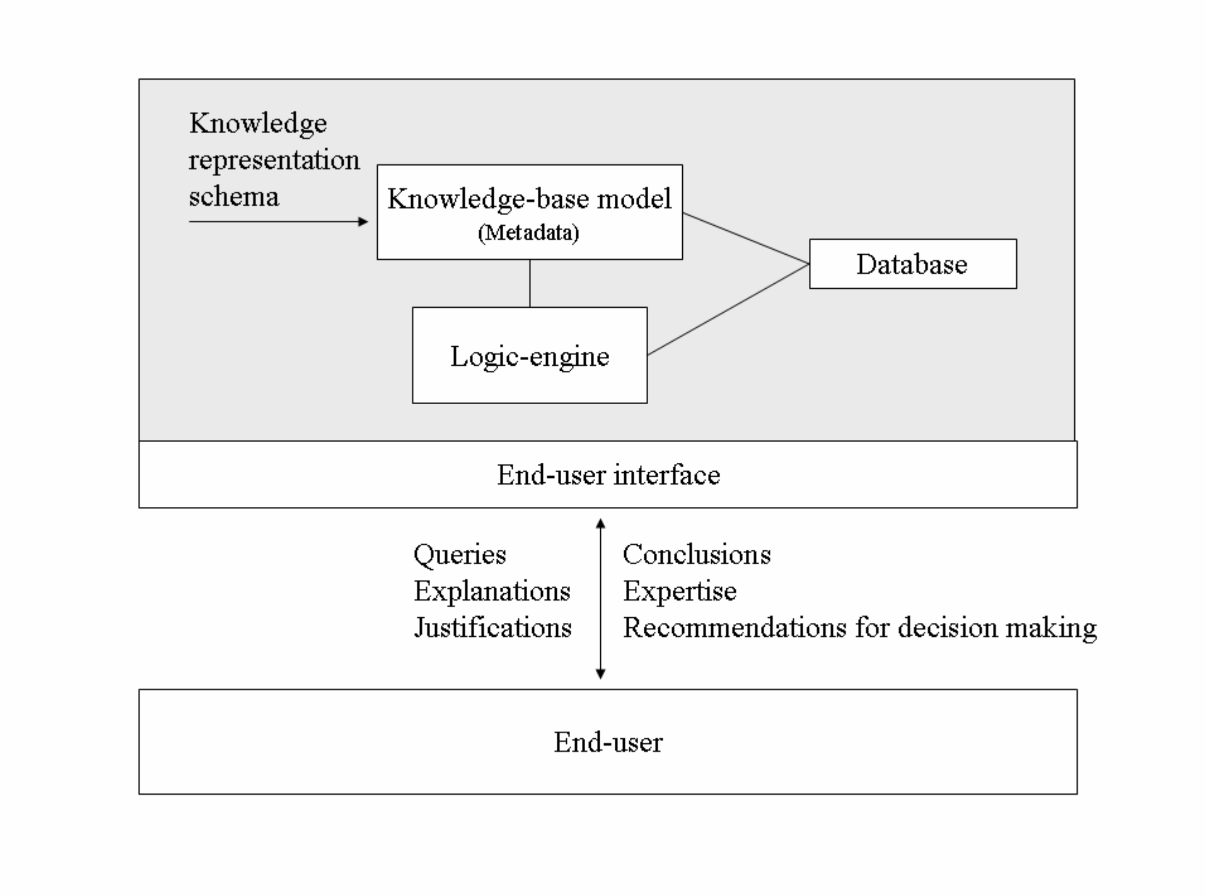
A knowledge-based model is a conceptual and logical representation of a problem in terms of significant entities in the problem domain and logical relations among them. It is a body of knowledge that has been organized within a formal syntactic and semantic framework, which allows formal inference about the problem at hand. The knowledge base identifies all modules, presents the organization of them, their attributes, and interactions; i.e. is a form of metadata base that is used to interpret data [Miller & Saunders 2002], [Reynolds *et al.* 2003], [Reynolds 2001], [Rodriguez-Bachiller & Glasson 2004], [Schmodlt & Rauscher 1996].

Logic paths in a knowledge base provide a formal data specification that is constructed as a cognitive map of the problem. The specification describes the data needed to perform an evaluation, and how the data are to be interpreted towards arriving at conclusions. Being a metadata base, the knowledge-based model ensures consistency in data interpretation across time and space, evaluating indicators against established reference conditions [Reynolds *et al.* 2003]. Knowledge-based models are also powerful tools for technology transfer. Knowledge bases encapsulate the expertise from those who know and make this knowledge available to people that not have the same level of knowledge. Moreover, the well-defined specification of syntax and semantics enables an easy communication to broad audiences and among involved stakeholders, which gives this approach great suitability for implementation [Reynolds *et al.* 2003], [Rodriguez-Bachiller & Glasson 2004]. This approach is "… perfectly appropriate to what is needed" [Rodriguez-Bachiller & Glasson 2004]: 48. Logic based analysis should not be seen as an approach directly competing with other, more traditional ones. But rather as an alternative methodology that can be used as logical framework for the integration of results from many specific mathematical models [Reynolds 2001].

Knowledge bases are one of the basic components of expert systems and decision support systems (see Rodriguez-Bachiller & Glasson 2004). Interpretation of data by a logic engine[12] provides a consistent evaluation of the state and processes represented in the knowledge-based model (see Fig. 12) [Reynolds *et al.* 2003]. Besides the advantages of knowledge based modeling, there is a high level of uncertainty inherent to the data and information sources. Uncertainty, can result from many factors, such as: imprecision intrinsic to the knowledge being used; data aggregation; as well as lack of sufficient accuracy in measurement instruments. Fuzzy logic is one approach that stands out toward dealing with uncertainty [Partridge & Hussain 1995].

[12] Also known as inference engine.

Figure 12. Basic components of decision support systems



Source: Adapted from [Partridge & Hussain 1995] and [Rodriguez-Bachiller & Glasson 2004].

Fuzzy logic is an important branch of applied mathematics that implements qualitative reasoning as a method for modeling lexical uncertainty and is concerned with quantification of set membership and associated set operations, and is an extension of Boolean logic. Fuzzy logic replaces Boolean truth values expressed in binary terms 0 or 1, with degrees of truth i.e. between and including 0 and 1. The degrees of truth are often confused with probabilities, although they are conceptually distinct, because fuzzy truth represents membership in vaguely defined sets, not likelihood of some event or condition [FuzzyTech 1999], [Reynolds 2001]. Formally:

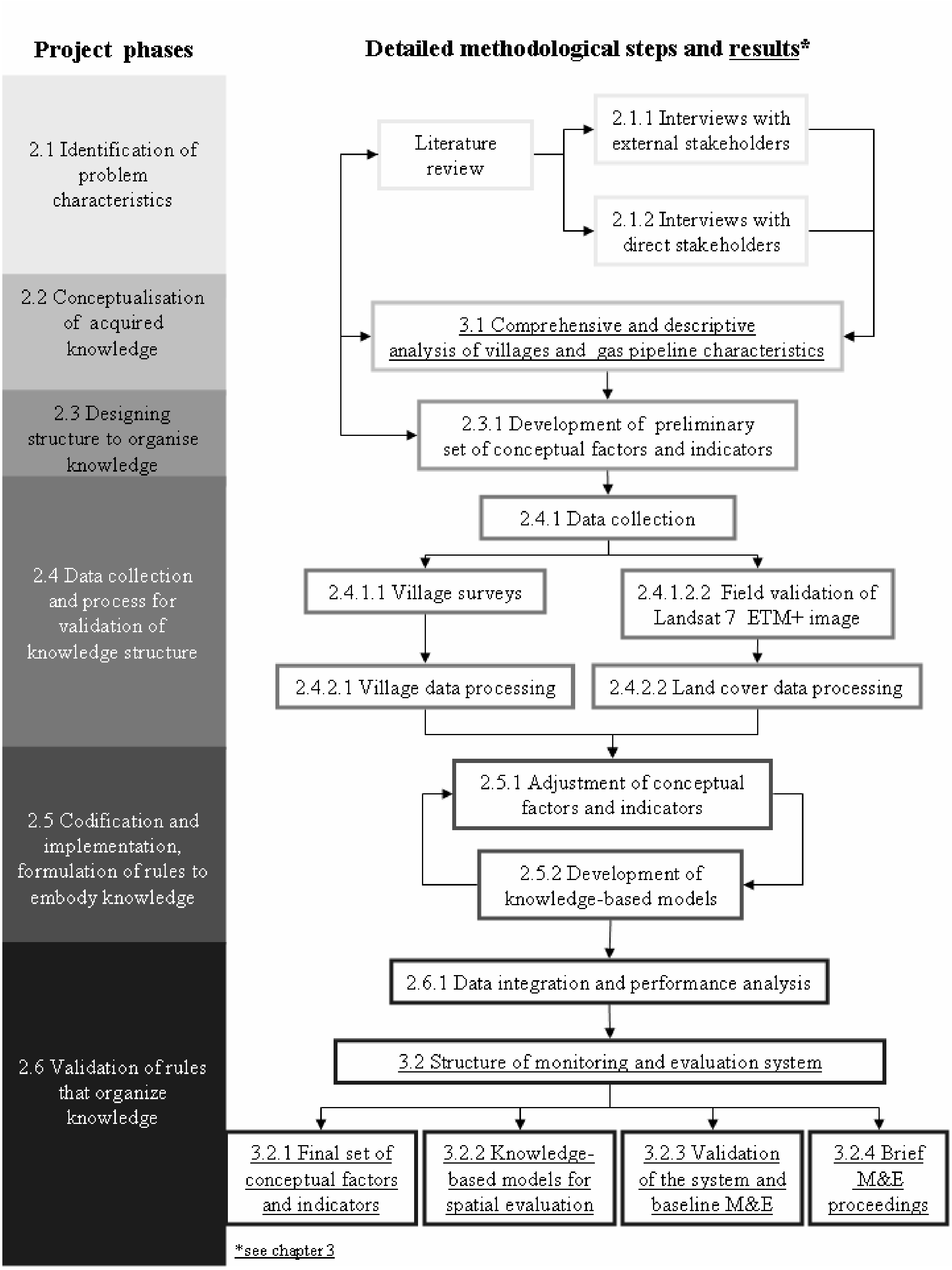
> "Let E be a set, denumerable or not, and let x be an element of E. Then a fuzzy subset A of E is a set of ordered pairs $\{x, \mu_{\mathrm{A}}(x)\}, \forall x \in E$ in which $\mu_{\mathrm{A}}(x)$ is a membership function that takes its values from the set $\mathrm{M} = [0, \quad 1]$ and specifies the degree of membership of x in A" [Kaufmann 1975].

"Nicht nur Beobachtungsgabe, sondern die Fähigkeit, seine Beobachtung zu verwerten, die Zusammenhänge zu erkennen und Schlüsse ziehen zu können, ist nötig, um Erfolg zu haben"
Robert Bosch

2 Methods

The general methods used for the design of the current monitoring and evaluation system consist of a six-phased approach modified according to various authors (see Fig. 13). Although they refer to it with different names, i.e.: "Expert systems design" [Rodriguez-Bachiller & Glasson 2004], "Systems development lifecycle" [Partridge & Hussain 1995],"Knowledge acquisition stages" [Jackson 1990], or" Knowledge engineering life cycle" [Buchanan *et al.* 1983], their approach is essentially the same. The design of the phases in a knowledge-based system must be carried out in parallel because each of them interacts with both the previous and subsequent phases; so a continual revision is required [Partridge & Hussain 1995]; [Schmodlt & Rauscher 1996]. The performed project phases can be seen on the left side of Fig. 13, indicated by filled rectangles; the corresponding detailed methodological steps as well as results (see Chapter 3) are indicated by empty rectangles and standard or underlined characters, respectively. The steps are depicted in a sequential fashion to keep things as simple as possible; however, the whole research project was characterized by high interaction and repetition of activities among phases.

Figure 13. Overview of methodological approach



Source: Author adaptation after [Andersen & Faris 2002], [Buchanan *et al.* 1983], [Jackson 1990], [Partridge & Hussain 1995], [Rodriguez-Bachiller & Glasson 2004].

2.1 Identification of characteristics of the problem

This section depicts the procedures applied to define the situation to monitor, as well as the sources and methods used for collecting both primary and secondary data in this phase of the research project.

2.1.1 Interviews with external stakeholders

Unstructured in-depth interviews were applied to the main external stakeholders[13] to find out about their concerns and judgments related to the issue of the present study, as well as to collect secondary data, which included published and unpublished references. Tables 1 to 3 summarize the institutions visited:

Table 1. Stakeholders at national level

Name	Institution's main objective	Type of institution	City of interview
Viceministerio de Energía e Hidrocarburos (VMEH)	Guide the national energy policies	Governmental	La Paz
Yacimientos Petroleros Fiscales Bolivianos (YPFB)	Fiscal and technical control of hydrocarbons exploration & production (upstream) operations (belong to VMEH)	Governmental	Santa Cruz
Superintendencia de Hidrocarburos	Grants management contracts to transport hydrocarbons (downstream operations) (belong to VMEH)	Governmental	Santa Cruz / La Paz
GasOriente Boliviano (GOB)	Gas transport company, owner of the Bolivian segment of the San Matías – Cuibá pipeline (Constituted by SHELL & Prisma Energy International[14])	Non-governmental	Santa Cruz
Instituto Nacional de Reforma Agraria (INRA)	Technical and executive management of the national agrarian reform policies	Governmental	Santa Cruz
Fundación Amigos de la Naturaleza Noel Kempff (FAN Bolivia)	Friends of Nature Foundation for the conservation of Bolivian biodiversity	Non-governmental	Santa Cruz

Source: Author's own compilation.

[13] I.e. situated outside the area of the gas pipeline's influence.
[14] Since 2003 instead of Enron.

Table 2. Stakeholders at regional level

Name	Institution's main objective	Type of institution	City of interview
Prefectura del Departamento de Santa Cruz	Executive government at regional level (Santa Cruz Department)	Governmental	Santa Cruz
GasOriente Boliviano (GOB)	Gas transport company, owner of the Bolivian segment of the San Matías – Cuibá's pipeline	Non-governmental	Santa Cruz
Fundación para la Conservación del Bosque Chiquitano (FCBC)	Bolivian Foundation for Conservation of the Chiquitano Forest, Bolivian Pantanal & Cerrado	Non-governmental	Santa Cruz
Wildlife Conservation Society (WCS Bolivia)	Wildlife Conservation Society Chapter eastern Bolivia	Non-governmental	Santa Cruz

Source: Author's own compilation.

Table 3. Stakeholders at local level

Name	Institution's main objective	Type of institution	City of interview
Central Indígena Turubó	Legal representation of the Chiquitano indigenous population	Non-governmental	San José de Chiquitos
Plan de Desarrollo Indígena (PDI)[15]	Management of the gas pipeline compensation program at village level	Non-governmental	San José de Chiquitos / Santa Cruz
Alcaldía de San José de Chiquitos	Executive government at municipal level / Management of the gas pipeline compensation program at municipal level	Governmental	San José de Chiquitos
Wildlife Conservation Society (WCS Bolivia)	Wildlife Conservation Society Chapter eastern Bolivia	Non-governmental	Santa Cruz

Source: Author's own compilation.

2.1.2 Interviews with direct stakeholders

As a result of meetings with the main external stakeholders and an exhaustive review of the available literature on the region, a lack of knowledge concerning the local specific conditions was identified. In Bolivia, the lack of research and systematization of information regarding rural areas represents a strong limiting factor to any research; this situation is even more profound in the lowlands. The collection of primary data was conducted using a standardized questionnaire[16]. A preliminary survey was performed before the actual administration of the questionnaire (May 2002). The preliminary survey aimed both establishing links with the

[15] See sections 3.1.2 and 3.1.3.

[16] Questionnaire can be obtained from author upon request.

mayors of each village and refining the questionnaire. Household-level interviews were performed in two case studies of the four villages located in the research area: Ramada (the most southern and nearest village to the main road Santa Cruz – Brazil) and San Juan de Chiquitos (the most inside the forest and northern village). Because the villages are small, it was attempted to interrogate as many households as possible, nevertheless many male household heads were absent at the moment of interviewing; a total of 41 male household heads were interviewed[17]. The survey provides primary data on: (a) farm management and trade of products, (b) socio-economic characteristics and land use, (c) possible positive and negative impacts from the gas pipeline, and (d) interactions of local people with changes brought about by the gas pipeline (see Table 4).

Table 4. Variables considered in the questionnaire for interviews with direct stakeholders

Variable	Type*	Measurement
Relationship between gas pipeline and motivation of moving to the village		
Original inhabitant	D	Living in this village the whole life
Migration		Reason of moving
• Related to the pipeline	D	
• Other	D	
Household characteristics		
Household size	C	Number of persons sharing the same house
Age	C	Age of household head
Education	C	Years of formal education
Labor resource		
Involvement in off-farm employment	C	Number of adults working in off-farm activities
Type of off-farm employment	N	Name of labor
Period of off-farm employment	C	Number of days at work per year
Farm characteristics and issues concerning the gas pipeline compensation program		
Farm workers	C	Number of adults working on the farm
Cultivation of fruit trees	C	Number of fruit trees
Cultivation of fruit trees	N	Name of fruit trees
Crops	N	Name of crops
Area of crops	C	Hectares per crop
Location of agricultural plot	O	Location according to tree categories: close to house, communal area, other
Cultivated area per household in year 2002	C	Total hectares
Cultivated area per household in year 1999	C	Total hectares
Current (2002) land cover of the plot cultivated in 1999	N	Name according to three categories: fallow, pasture, other
Cropping years in year 2002	C	Number of cropping years on the same plot
Cropping years in year 1999	C	Number of cropping years on the same plot
Current (2002) plot cultivated was financed by the gas pipeline compensation program	D	Existence of relationship between clearing of forest for agriculture and gas pipeline

[17] In Ramada 13 households of the total 15. In San Juan de Chiquitos 28 households of the total 45.

Name of gas pipeline compensation benefit:		Participation in benefits provided by gas pipeline company
• Cattle credit	D	
• Credit for expansion of agricultural lands	D	
• Improved seeds	D	
• Training	D	
• Wire	D	
• Tools	D	
• Poultry	D	
• Pigs	D	
• Road maintenance	D	
• Others	D	
Livestock holding (not related to gas pipeline compensation):		Number of animals
• Poultry	C	
• Cattle	C	
• Horses	C	
• Donkeys	C	
• Pigs	C	
Grazing area		Type of area used for grazing
• Paddock	N	
• Forest	N	
• Fallow	N	
Kilometers roamed by cattle	C	Maximum distance roamed by cattle
Paddock	D	Holding of paddock
Paddock area	C	Total held hectares
Cleared plot:		Type of vegetation cleared for agriculture
• Fallow	N	
• Forest	N	
Hunting		
Hunter	D	Household head practices hunting
Game animals	N	Name of game animals
Hunting location:		Type of area used for hunting
• Forest	N	
• Agricultural land	N	
Hunting frequency	C	Monthly frequency of chasing
Game trade	D	Existence of game trade
Kilometers roamed for hunting	C	Maximum distance walked for chasing
Use of the gas pipeline right of way for hunting	D	Existence of use of the gas pipeline right of way for hunting
Fuel wood		
Fuel used for cooking	N	Name of the fuel
Use of fuel wood	C	Daily frequency of fuel wood use for cooking
Fuel wood collection	N	Place of fuel wood collection
Fuel wood consumption	C	Cubic meter of fuel wood used weekly
Kind of fuel wood used	N	Name of the tree used as fuel wood
Kilometers walked for fuel wood collection	C	Maximum distance walked for fuel wood collection
Farm production commercialization		
Name of farm product	N	Name of commercialized farm product
Units	C	Commercialized units
Place of trade	N	Place of trade
Logging		
Trade of timber	D	Existence of timber commercialization
Engagement in logging activities	C	Year of first engagement in logging activities

Logging species	N	Name of logged trees
Number of logged trees	C	Monthly number of logged trees
Diameter at breast height (DBH) cutting limit	C	Minimum DBH cutting limit applied
Use of the gas pipeline right of way for logging	D	Existence of use of the gas pipeline right of way for logging
Support by other programs besides the gas pipeline compensation (between 1999 and 2002)		
Participation in other programs	D	Existence of participation in other social or productive programs, reflecting if the household already receives some kind of aid
Institution	N	Name of institution
Kind of aid	N	Name of aid
Year of aid	O	Year of received aid

* C= Continuous variable, D = Dummy variable, O = Ordinal variable, N = Nominal variable.

2.2 Conceptualization of acquired knowledge

Descriptive statistics were employed to break down the primary data and to obtain pertinent information; frequencies, means, ratios and percentages were computed for different variables. The data analysis was carried out using SPSS 11.5 for Microsoft Windows®.

2.3 Designing structure to organized knowledge

2.3.1 Development of a preliminary set of conceptual factors and indicators

The knowledge acquired in phases 2.1 and 2.2 was arranged in a preliminary set (see Table 5). It consists of twenty-seven indicators corresponding to eight conceptual factors associated with land use, as well as the environmental conditions in the research area.

Table 5. Preliminary set of factors and indicators

Conceptual factors	Indicator description
Absence of settlement policies	Localization of new settlement approved by government
Incentives for agricultural production expansion	Distance to all-year road Travel time to all-year road Amount of financial incentives of gas company for new clearing of forest Area of land with clear property rights
Ecosystem status	Size class distribution of human landscapes Number of news breaches in the intersections of roads with right of way
	Number & localization of forest fires Regeneration of vegetation at the edge of right of way Number of seed stock & shading trees per ha of agricultural land Mm of precipitation
Intensification of agriculture	Kg of cash crops Period of fallow Use of improvement seeds Type of fertilizer used Area under irrigations systems
Population	Number of (male) household heads with permanent off-farm job Number of new households
Hunting	Number of animals consumed monthly Animal species consumed monthly Hunting distance from villages
Logging	Number of logged trees monthly Name of logged trees Use of wood
Extensification of herding	Amount of cows Amount of PDI’s cows Area of pastures

2.4 Data collection and processing for validation of knowledge structure

2.4.1 Data collection

The information for validating the above knowledge structure or *preliminary set of factors and indicators* (Table 5) was obtained from two main sources: (a) the village survey and (b) the land cover data.

2.4.1.1 Village survey

Between July-August 2003, a survey in the four villages located in the research area was conducted in two parts: household interviews and interviews with the leaders of the indigenous population development program (PDI: abbreviation of its Spanish name “Programa de Desarrollo Indígena”) cattle groups. Village boundaries (including agricultural and housing areas) were demarcated using a Garmin Etrex GPS unit to record the respective reference points.

2.4.1.1.1 Household interviews

A standardized questionnaire[18] was used to collect the primary data. It was attempted to interrogate all households to greatest degree of completeness possible (see Table 6). Table 7 presents the variables and their corresponding measurements used in the questionnaire.

Table 6. Number of interviewed households per village

	Entre Ríos	Ramada	San Juan de Chiquitos	Buena Vista	Total
Interviewed households	11	13	30	72	126
Total of inhabited households	11	15	45	99	170

[18]Questionnaire can be obtained from author upon request.

Table 7. Variables considered for validation of the preliminary set of factors and indicators in the households' interviews

Variable	Type*	Measurement
Household head and household characteristics		
Name	N	Name of household head
Age	C	Age of household head
Education	C	Years of formal education
Household size	C	Number of people who share the same house
Labor resource		
Off-farm employment	D	Involvement in off-farm employment
Type of off-farm employment	N	Name of labor
Period of off-farm employment	C	Number of months worked per year
Farm characteristics		
Crops	N	Name of four most important crops of the respective year
Area of crops	C	Hectares of crops
Kilo per crop	C	Total of harvested kilos per crop
Kilo of commercialized crop	C	Total kilos of commercialized crops
Place of commercialization	N	Name of place
Kind of seeds used		Kind of seeds used
• Keep part of the harvested crop	D	Old seed
• Improved seeds	D	Improved seed
Agrochemicals	D	Use of agrochemicals
Irrigation	C	Hectares under irrigation
Fallow	D	Practice of fallow
Period of fallow	C	Years of fallow of one plot
Cattle holding		
• Cattle (non-related to gas pipeline compensation)	C	Number of animals
Field for grazing		Type of field used for grazing
• Paddock	N	
• Forest	N	
Paddock (non-related to gas pipeline compensation)	D	Holding of paddock
	C	Total held hectares
Hunting		
Hunting frequency	C	Frequency of hunting in the last 4 weeks
Game animals	N	Names of the game animals
Number of animals	C	Number of animals hunted in the last 4 weeks
Kilometers roamed for hunting	C	Distance roamed for hunting
Logging		
Trade of timber	D	Existence of timber commercialization
Engagement in logging activities	C	Year of first engagement in logging activities
Logging species	N	Name of logged trees
Number of logged trees	C	Number of trees logged in the last 4 weeks
Timber use	N	Use given to the timber

* C= Continuous variable, D = Dummy variable, O = Ordinal variable, N = Nominal variable.

2.4.1.1.2 Interviews with leaders of PDI's cattle groups

A standardized questionnaire[19] was used to collect primary data related to PDI's cattle holding (see Table 8). Because working groups manage these cattle, they were regarded outside of the household interviews in order to prevent overestimation of the total number of cattle (i.e. by counting the same animals repeatedly). For this purpose, short interviews were carried out only with the leaders of the PDI's cattle groups.

Table 8. Variables considered for validation of the preliminary set of factors and indicators in the leaders of PDI's cattle groups' interviews

Cattle holding		
PDI's cattle	C	Number of animals
Field for grazing		Type of field used for grazing
• Paddock	N	Paddock
• Forest	N	Forest
PDI's paddock	D	Holding of paddock
Hectares	C	Total held hectares

* C= Continuous variable, D = Dummy variable, O = Ordinal variable, N = Nominal variable.

2.4.1.2 Land cover data

This section presents the procedures applied to obtain the current land cover information from satellite images.

2.4.1.2.1 Data acquisition and description

Initially, geo-referenced Landsat 7 ETM+ data for the year 2002 were used, provided by the FCBC. The image was recorded on 26 September, 2002 and corresponds to path 228 and row 072 of the WRS-2 system .

The satellite Landsat 7 was launched in April 1999; it holds the Enhanced Thematic Mapper Plus (ETM+), an eight-band multispectral scanning radiometer that provides high-resolution imaging information of the Earth's surface [NASA 2005], Tables 9 and 10 illustrate the most important characteristics of the satellite and its multispectral radiometer.

[19] Questionnaire can be obtained from author upon request.

Table 9. Specifications of Landsat 7 (ETM+)

Altitude	705 km
Inclination	98°
Orbit	Polar, sun synchronous
Equatorial crossing time	10.00 a.m. (descending node)
Period of revolution	99 m
Repeat coverage	16 days

Source: [NASA 2005]

Table 10. Radiometric characteristics of Enhanced Thematic Mapper (ETM+)

Spectral bands	Wavelength (microns- µm)	Spatial resolution (m)
1	0.45-0.52	30
2	0.52-0.60	30
3	0.63-0.69	30
4	0.76-0.90	30
5	1.55-1.75	30
6	10.42-12.50	60
7	2.08-2.35	30
8	0.52-0.90	15

Source: [Leica Geosystems GIS & Mapping 2003]

2.4.1.2.2 Field validation

During the village survey (July-August 2003), field reference points corresponding to the land cover types of interest were recorded, using a Garmin Etrex GPS unit. These reference points were used afterwards to choose training sites in the supervised classification of the Landsat 7 ETM+ image (see section 2.4.2.2.2).

2.4.2 Data processing

2.4.2.1 Village data processing

2.4.2.1.1 Quantitative data

Descriptive statistics were employed to analyze the primary data; frequencies, means, ratios and percentages were computed. The data analysis was carried out using SPSS 11.5 for Microsoft Windows®.

2.4.2.1.2 Spatial data

By using GIS[20], village boundaries were digitized utilizing reference points, which were superposed on the Landsat 7 ETM+ image. In this way a vector data layer was created to represent the village areas. Furthermore, corresponding vector data layers were generated to represent the respective spatial indicators: a) potential area of fuel wood collection, b) potential area of logging, and c) potential area of browsing. The infrastructure (i.e. roads and gas pipeline) vector data layer from [Céspedes *et al.* 2002] was included and complemented with field data. For each vector data layer, related quantitative data were entered for later performance analysis of knowledge-based models.

2.4.2.2 Land cover data processing

2.4.2.2.1 Pre-processing

The Landsat 7 ETM+ image was already enhanced by the method of Brovey Transform [Padilla 2004], at the GIS lab of the FCBC. The method is used to visually increase contrast in the low and high ends of an image's histogram [Leica Geosystems GIS & Mapping 2003].

A subset corresponding to the research area was split off the Landsat 7 ETM+ image in order to minimize the amount of data for processing. No atmospheric corrections or topographic normalization were required since the image did not display clouds, and because of the flat topography of the terrain (see Fig. 8).

[20] ArcGIS Desktop version 8.3 was used.

2.4.2.2.2 Extraction of thematic information: land cover map

Three land cover classes of interest were defined: (see Section 3.2.1.4): (a) deforested areas, (b) open canopy areas, and (c) closed canopy areas.

A supervised classification was carried out using all spectral bands[21]. Training sites were verified with ground truth data (reference points and personal field observation). A Maximum-likelihood classification was employed using the respective spectral response pattern of each defined land cover class, (i.e. the degree to which an object reflects incident electromagnetic energy in different regions of the electromagnetic spectrum). The Maximum-likelihood classification algorithm considers that the pixel values of each class conform to a normal distribution, and assigns the actual distribution of pixel values in one class X, calculating the probability that one pixel (with a given pixel value) belongs to this class X [Chuvieco 2000], [Jensen 1996]. The percentage of overall accuracy of the supervised classification was 92.29% (Table 11).

Table 11. Error matrix of supervised classification

Classification	Closed canopy areas	Open canopy areas	Deforested areas	Row total
Closed canopy areas	99.37	0.00	0.25	99.63
Open canopy areas	0.58	0.00	76.27	76.85
Deforested areas	0.01	100.00	0.39	100.40
Column total	99,96	100.00	76.92	276.88
Overall accuracy	276.88/3= 92.29%			

The classified image was exported into a vector data layer for posterior GIS-analysis and integration with village data[22] (see Section 3.2.3.2).

[21] Within the software environment: ERDAS IMAGINE 8.6.
[22] Within the software environment: ArcGIS Desktop version 8.3.

2.5 Codification and implementation, formulation of rules to embody knowledge

2.5.1 Adjustment of factors and indicators

Developing a knowledge base model implies building a meaningful representation of knowledge [Partridge & Hussain 1995]. After data collection and processing, the preliminary set of factors and indicators was adjusted and refined to obtaining a validated set of factors and indicators (Table 12)[23]. It was also necessary to refine some indicators by dividing them into sub-indicators.

Table 12. Comparison of both the preliminary and validated set of factors and indicators

Preliminary set		**Validated set**		
Factors	Indicator description	*Factors*	Indicator description	Sub-Indicator description
Intensification of agriculture	Area under irrigation	*Level of agricultural intensification*	Technological level	Percentage of households that use improved seeds
				Percentage of households that use agrochemicals
				Area under irrigation
				Type of tools utilized
	Period of fallow		Percentage of households not practicing fallow	
	Use of improvement seeds		Mean land area used per household	Cultivated area of pastures per interviewed household
				Housing and crops areas per inhabited house
	Type of fertilizer used	*Level of agricultural commercialization*	Proportion of commercialized farm production	Percentage of commercialized crop production per household
	Kg of cash crops			Percentage of commercialized cattle production per household
Extensification of herding	Number of cows	*Cattle*	Number of browsing cattle	
	Number of PDI's cows		Potential area of browsing	
	Area of pastures			
Absence of settlement policies	Localization of new settlement approved by government			
Incentives for agricultural	Distance to all-year road	*Incentives for tree logging and agricultural*	Average traveling speed on all-year road	
	Travel time to all year road			

[23] For explanation of indicators exclusion, see Appendix I.

production expansion	Amount of financial incentives from gas company for new clearing of forest Area of land with clear property rights	*production expansion*	Provision of financial incentives by gas company for the expansion of agricultural lands	
Ecosystem status	Size class distribution of human landscapes Number of news breaches in the intersections of roads with right of way Number and localization of forest fires Regeneration of vegetation at the edge of right of way Number of seed stock & shading trees per ha of agricultural lands Mm precipitation	*Land cover*	Deforested areas Natural vegetation areas	Deforested areas Infrastructure Open canopy areas Closed canopy areas
Population	Number of new households Number of (male) households heads with permanent off-farm jobs	*Population*	Number of inhabited houses Fuel wood consumption per household Potential area of fuel wood collection Percentage of manpower with potential employment in logging	
Hunting	Number of animals consumed monthly Animal species consumed monthly Catch distance from villages			
Logging	Name of logged trees Number of trees logged monthly Use of wood	*Logging*	Potential area of logging Number of trees logged monthly Main use given for the timber	

2.5.2 Development of knowledge-based models

The development of the knowledge-based models was performed under the software environment "NetWeaver logic engine"[24]. The engine is a Microsoft Windows® dynamic link

[24] Developed by Rules of Thumb, Inc. (version 16.3.2).

library (DLL). To represent information, NetWeaver's knowledge bases are supported on object-oriented networks and fuzzy-logic [Miller & Saunders 2002].

A *network* is a graphical and hierarchical depiction of a rule or set of rules and their relationships [Partridge & Hussain 1995], [Saunders *et al.* 2002]. The term *object-oriented* corresponds to information abstraction and encapsulation, i.e. the representation is done in a modular way by an object, which is relatively autonomous and has its own specifications and procedures to perform definite requested tasks [Partridge & Hussain 1995], [Schmodlt & Rauscher 1996].

NetWeaver employs dependency networks (see Fig. 14); representing knowledge about how to solve a problem (i.e. how to evaluate topics of interest in an assessment) in terms of the topics of interest in the problem domain, and the relationships (dependencies) among these topics. There are two basic types of objects: (a) the topic (green ovals in Fig. 14), and (b) the data link, both being represented in the network structure by a programming object.

The NetWeaver *data links* undertake the retrieval, storage and interpretation of data and nodes that are mathematics or logic operators. There are simple or calculated data links:

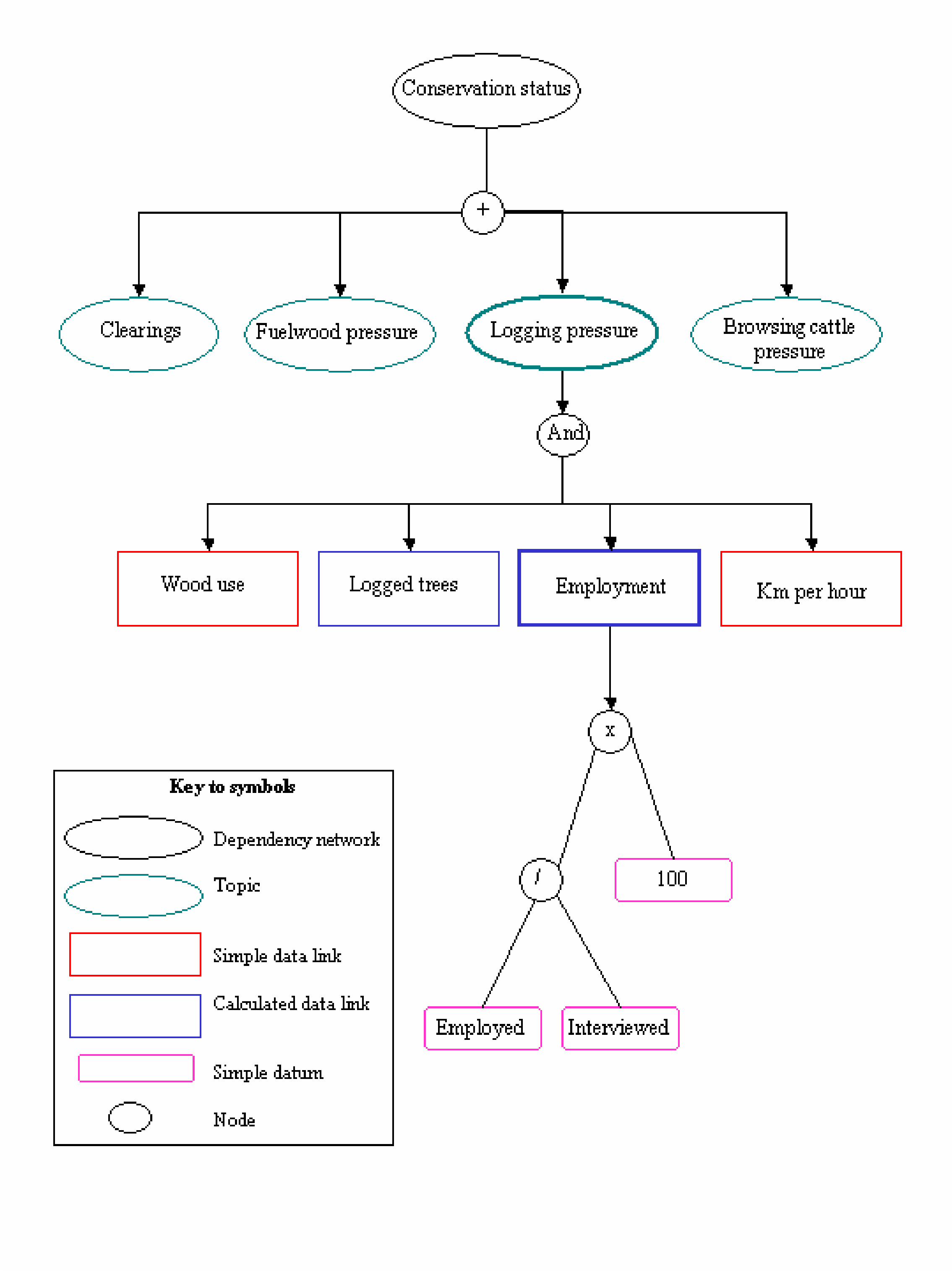
- *Simple data links* can either compute a truth-value by evaluating the data value against an argument list (red rectangles in Fig. 14) or can read a data value that it passes to another data link without evaluation (pink rectangles in Fig. 14).
- *Calculated data links* (blue rectangles in Fig. 14) transform input data. It can hold either a truth-value or a data value that it passes directly to another calculated data link without evaluation. A calculated data link has nodes hanging from it that connect two or more data links or networks.

Both data links, simple or calculated, compare data to *rules* or arguments, and compute a value based on this comparison ranging from -1 to 1, where –1 corresponds to a false value and 1 to a true value. There are two types of *arguments*: crisp arguments and fuzzy arguments.

- A *crisp argument* converts its data link's value into a Boolean result, which is either into a true or false result.

- A *fuzzy argument* builds a fuzzy curve to compare to the data contained in its data link and gives a fuzzy result ranging from false to true [Miller & Saunders 2002].

Figure 14. Example of hierarchical arrangement of dependency networks



Based on the NetWeaver software architecture, two independent knowledge-based models were developed in a cyclic process. The first, the *Village-level knowledge-based model* corresponds to those indicators and sub-indicators that take place within village boundaries. In this case they match all conceptual factors related to agricultural activities: *level of agricultural intensification and level of agricultural commercialization*. The model consists of one dependency network identified as the "Agricultural pressure network". Comparing Tables 13 and 14, it can be seen that, for instance, the conceptual sub-indicator "Percentage of households using improved seeds" is represented in the model by the data link "No seeds" (see Section 3.2.2.1.). The data links are connected through an average node (see Fig. 29), i.e. the agricultural pressure on woodlands is an average of all the indicators and sub-indicators (for model details see Section 3.2.2.1).

Table 13. Conceptual factors their indicators and sub-indicators with influence at village-level

Table 14. Village-level knowledge-based model structure

Conceptual factors	Indicators	Sub-indicators		Data link name	Topics	Dependency network
Level of agricultural intensification	Technological level	Percentage of households using improved seeds	→	No seeds	-	Agricultural pressure
		Percentage of households using agrochemicals	→	No agrochemical		
		Area under irrigation systems	→	No irrigation		
		Type of tools utilized	→	No mechanization		
	Percentage of households not practicing fallow		→	No fallow		
	Mean land area used per household	Cultivated pasture areas per interviewed household	→	Pasture		
		Housing and crops areas per inhabited house	→	Housing & crops		
Level of agricultural commercialization	Proportion of commercialized farm produce	Percentage of commercialized crop production per household	→	Crop production		
		Percentage of commercialized cattle production per household	→	Cattle production		

The second model or *Meso-level knowledge-based model* corresponds to such indicators and sub-indicators having an effect beyond the village boundaries, and belonging to the following conceptual factors: *incentives for tree logging and agricultural production expansion, land cover, population and cattle*. A rearrangement of indicators and sub-indicators was necessary (compare Tables 15 and 16), because they represent dissimilar areas of influence. These areas of influence differ in some cases of the corresponding conceptual factor; for a GIS analysis the spatial component prevails.

The model consists of one dependency network, “Conservation status network”, and four topics: (a) “Clearings“, (b) “Fuelwood pressure”, (c) “Browsing cattle pressure“, and (d) “Logging pressure”. The topics are connected through a sum node as shown in Fig. 36, i.e. the conservation status corresponds to the sum of the topics' partial results (for model details see Section 3.2.2.2). The respective data links were assigned to values between 0 and 1 to calculate the sum of all the topics' partial results. If the partial results were allowed to be negative, they would have a negative impact on the sum. Therefore after calculating the sum; Therefore after calculating the sum, it has to be rescaled to the NetWeaver range of values (-1…1) by setting the range borders as depicted in Fig. 15, where in the left pair the value of zero (0) (indicated as *undetermined* in the left most square) is set to false (-1), and in the right pair the value of one is set to true (+1).

Table 15. Conceptual factors their indicators and sub-indicators with influence at meso-level

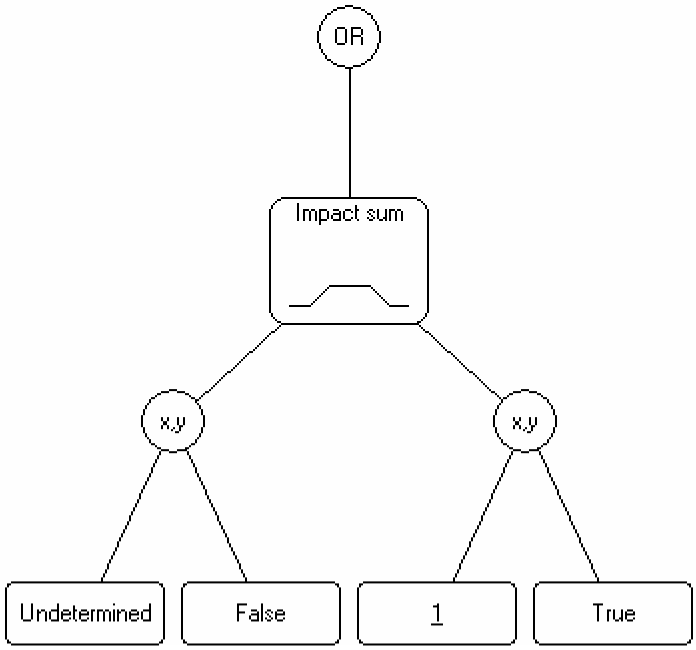
Conceptual factors	Indicators	Sub-indicators
Incentives for tree logging and agricultural production expansion[25]	Average traveling speed on all-year road	
		Infrastructure
Land cover	Deforested areas	Deforested areas
	Natural vegetation areas	Open canopy areas
		Closed canopy areas
Population	Number of inhabited houses	
	Fuel wood consumption per household	
	Potential area of fuel wood collection	
	Percentage of manpower with potential employment in logging	
Logging	Potential area of logging	
	Number of trees logged monthly	
	Main use given of the timber	
Cattle	Number of browsing cattle	
	Potential area of browsing	

Table. 16 Meso-level knowledge-based model structure

Data link name	Topics	Dependency network
Km/h	Logging pressure	
Infrastructure	Clearings	
Land cover type	Clearings Fuel wood pressure Browsing cattle pressure	
Households		
46.44[26]	Fuel wood pressure	
Fuel wood area		Conservation status
Employment	Logging pressure	
Logging area	Logging pressure	
Logged trees	Logging pressure	
Wood use		
Cattle	Browsing cattle pressure	
Browsing	Browsing cattle pressure	

[25] The indicator "Provision of financial incentives by Gas Company for the expansion of agricultural lands" leaves out of any dependency network, for details see description of this indicator in Section 3.2.1.3.2.
[26] This is a constant value corresponding to the annual fuel wood consumption per household.

Figure 15. Rescaling scheme



2.6 Validation of rules that organize knowledge

2.6.1 Integration of data layers and performance analysis of knowledge-based models

Data processing and the development of knowledge-based models, as described in Sections 2.4.2 and 2.5.2, were carried out in a cyclic readjustment process simultaneously with the performance analysis. Data layers as well as knowledge-base models were integrated by using the Ecosystem Management Decision Support System (EMDS)[27], which is an extension of ArcMap Desktop. The Analysis subsystem of the EMDS Assessment system is the interface to the NetWeaver logic engine. Directed by the Analysis subsystem, the NetWeaver logic engine processes the *dependency networks* of the *knowledge base* to produce an assessment of ecosystem states or processes of interest.

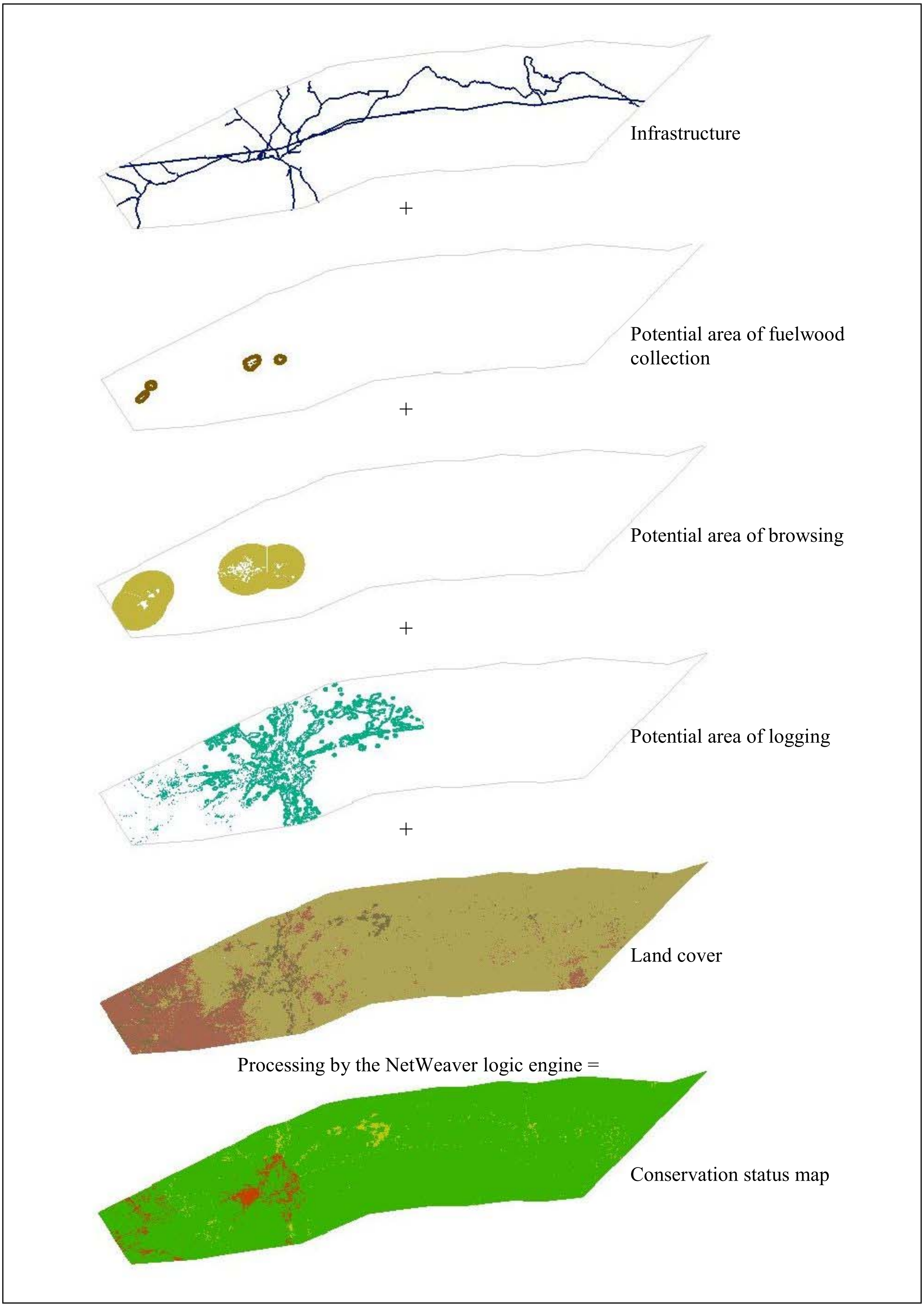
EMDS is an application framework for knowledge-based decision support of ecological assessments at any geographic scale. The system integrates a state-of-the-art geographic information system (GIS) -ArcMap Desktop- as well as knowledge-based reasoning -NetWeaver logic engine- and decision modeling technologies –Criterium DecisionPlus[28]- in the Microsoft Windows® environment. The EMDS Project Environment is the primary

[27] The EMDS system is a product of the US Department of Agriculture Forest Service.
[28] Criterium DecisionPlus not was used in this research project.

component of the extension with which the user interacts to set up assessments, analyses and scenarios. ArcMap itself provides the resource manager with a powerful GIS environment in which to visualize, create, process, and display spatial information. ArcMap handles all EMDS spatial displays, as well as where a user assembles all the necessary data layers to be processed by the NetWeaver logic engine [Reynolds 2003].

The villages' areas data layer and the village- level knowledge-based model were integrated. The model was run to perform the evaluation of agricultural pressure on the surrounding forest. Necessary adjustments on the model were carried out. This process was repeated several times until the required performance standard was accomplished. Subsequent to integration of the meso-level knowledge-base model with the respective data layers (infrastructure, potential area of fuel wood collection, potential area of logging, potential area of browsing, and land cover; see Fig. 16), the same process was executed with the evaluation of the conservation status. Additionally, each partial evaluation (deforested areas, fuel wood pressure, cattle pressure, and logging pressure) was executed to ensure the performance of individual dependency networks. In this interactive way, the validation of the system and the baseline M&E results were accomplished.

Figure 16. Data layers used for the performance analysis of the meso-level knowledge base model



"The whole is more than the sum of its parts"
Aristotle

3 Results and discussion

This chapter presents both the characteristics of the problem in the research area and the structure of the system for monitoring and evaluation the conservation status of forest.

3.1 Comprehensive and descriptive analysis of villages and gas pipeline characteristics

Beyond the actual transportation of gas, a gas pipeline can be associated with several other issues. In the Bolivian context two issues were identified[29]: (a) pipeline right of way and (b) gas company compensation programs.

3.1.1 The right of way

The right of way is a corridor of 633km length and 15m breadth (30m during the construction phase) that was totally cleared (see Appendix II). The Bolivian segment of the pipeline is 361.1km long, with most of this crossing forest ecosystems. GOB contracted the services of the Museo de Historia Natural Noel Kempff Mercado to reforest 26.5km of the right of way[30] [MHNNKM 2002]. These areas, which are considered vulnerable, correspond to intersections with the single permanent river and roads (see Fig. 1). The rest, 335.5km, were left without management activities, and natural regeneration of the vegetation is expected. Fig. 17 shows

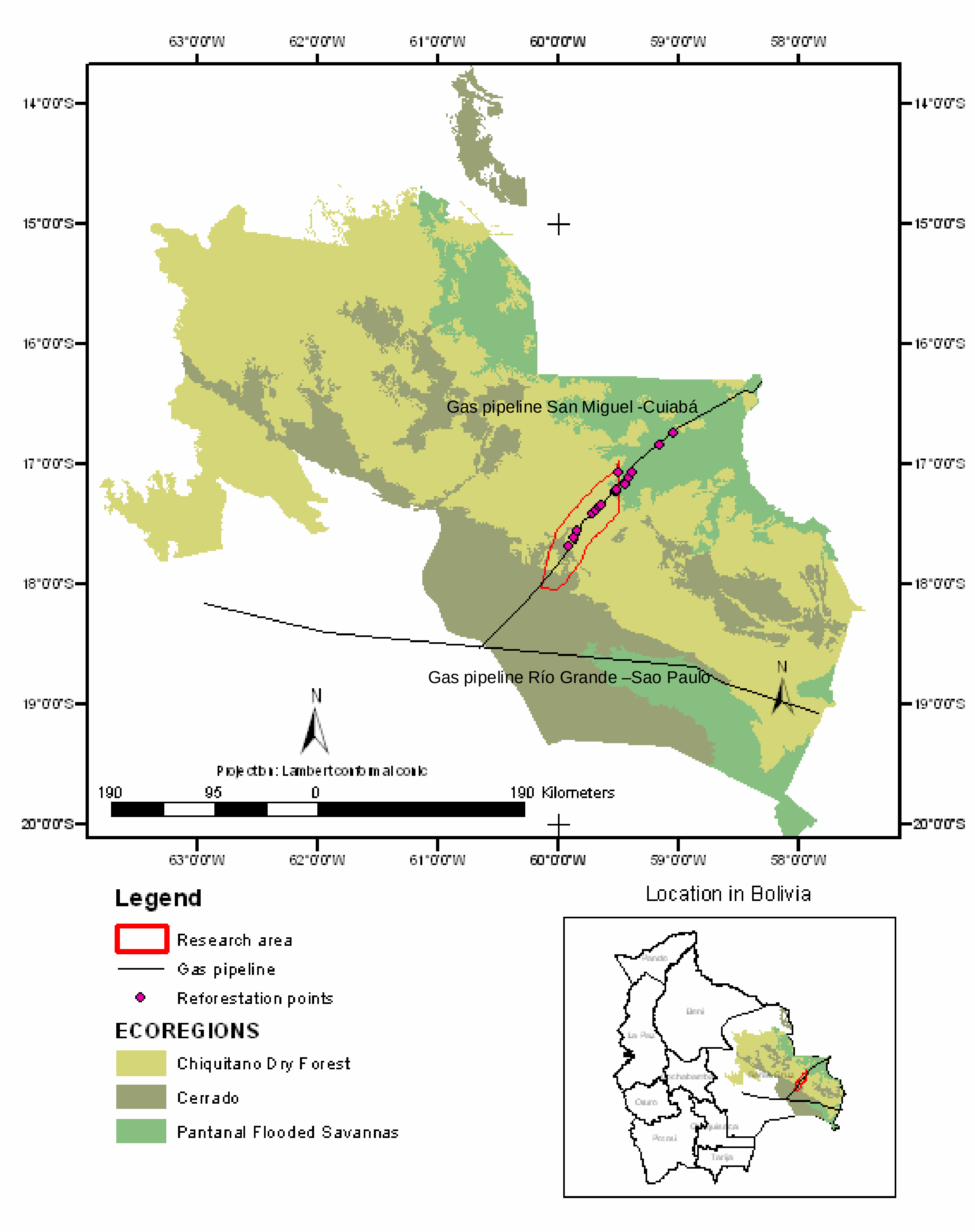
[29] No fiscal revenues from the gas pipeline flow into the area; revenue from the pipeline reaches the region only in an indirect way. The royalties, which amount to 11% of the total production of gas by department, correspond to the whole Santa Cruz Department. The royalties are distributed according to the population of each municipality (Article 50 [Ley de Hidrocarburos 1996]), (Article 21 [Ley de Participación Popular 1994]). Reviewing the expenditure reports of San José Municipality, it was observed that most of the budgets are expended in the capital of the municipality; rural areas remain out of reach of important investments. Also, sales of gas to Brazil are exempted from payment of taxes [Ley de 23 de Enero de 1997].

[30] These reforestation activities permitted the acquisition of some knowledge about floristic and vegetation characteristics of the dry forest, which still is poorly investigated.

the deforested areas in 2002. Adjacent to the right of way, “non-important deforestation”[31] can be observed.

[31] Non-important deforestation means less than 225m², corresponding to spatial resolution (15 x 15m) of Landsat EMT+ imagery.

Figure 17. Types of land cover crossed by the Bolivian segment of San Miguel- Cuiabá gas pipeline



Source: Ecoregion and gas pipeline data adopted from [Ibisch & Reichle 2002], reforestation points from [MHNNKM 2002]

3.1.2 Gas company compensation programs

Both the executive government at municipal level, as well as villages influenced by the gas pipeline construction were compensated through the implementation of two programs by GOB. Both programs were oriented towards (at least in a temporary way) the local development and had a nonrecurring character.

3.1.2.1 Municipality level program

The Bolivian segment of the right of way crosses two municipalities: “San José de Chiquitos” in the southwest part and “San Matías” in the northeast. The research area is located in San José de Chiquitos, a municipality on which the program spent around one million $US. It consisted of a total of fifteen projects which were divided into six work areas [Alcaldía de San José 2002], [URS/Dames & Moore 2001], as follows:

(a) Supply of electricity generators: for one village (Taperas, which lacked of electricity until that moment) and the municipal capital (San José)
(b) Building of water supply systems: for two villages (Buena Vista and San Juan de Chiquitos, which lacked any water supply until this moment) as well as the construction of a water tank (San José).
(c) Cultural support: consisted of funds to conclude the building and equipment of a House of Culture (San José), restoration of a Jesuit Church (San José), and accomplishment of archaeological research.
(d) Educational support: included building a school in one village (Taperas), as well as the construction of a school, a center for handicapped children, and a technical school for carpentry, electricity, mechanics, and welding in San José.
(e) Public health support: construction of an infirmary (Taperas) and a hospital (San José)
(f) Cattle raising support: establishment of agricultural extension programs for control of aphthous fever and cattle genetic improvement by incorporation of stock breed.
(g) Handicraft support: creation of a rotating fund to finance brick makers and carpenters (San José).

The municipality level program does not appear to be a significant threat for the conservation of the Chiquitano Dry Forest. The present research directed more attention to the village level program, because it was carried out in villages located in the forest, and because the program components there were more related to land use.

3.1.2.2 Village level program (PDI)

The village level program, also known as the indigenous population development program, was designed for compensation of the villages located within 10km of either side of the right of way, which is defined as “area of indirect influence.“ The program input around two million $US and was made up of three components. Based on projects designed by the villages themselves, the components were the following:

(a) Projects related to expansion of agriculture, poultry farming, cattle raising, and handicrafts;
(b) Land entitlement, which conducted and financed the process of clarifying land rights until obtaining the property rights; and
(c) A capacity building plan, towards improving local organizational strength [GasOriente Boliviano (2003)], [URS/Dames & Moore 2001].

Five villages belonging to the San José de Chiquitos municipality[32] profited from the program, which was managed by the indigenous organization “Central de Comunidades Indígenas Chiquitanas TURUBÓ”.

3.1.3 Village features vs. PDI and right of way issues

Most of the inhabitants of the villages located in the research area, namely Ramada, Entre Ríos, Buena Vista, and San Juan de Chiquitos (see location in Fig. 9), belong to the “Chiquitano“ ethnic group. The Chiquitanos correspond to the largest ethnic group in the region (in 1994 around 44 000 inhabitants). Their origin dates from a miscegenation process that started at the end of the 17-century, when the Jesuits came to the region and settled a mixture of ethnic groups in the denominated “Jesuit Reductions“. These groups did not fight against the missionary work and were converted to the Catholicism [APCOB 2002].

[32] One village is located outside forest ecosystems and therefore was excluded from the research area.

Today, their culture is made up of a mixture of native and Christian elements. The Chiquitanos were originally farmers, hunters, and collectors; the Jesuits introduced the keeping of domestic animals. Currently they practice the shifting cultivation and holding of domestic animals, mainly for subsistence purposes. The land is communal property and hunting is still important in many households. Additional possibilities to earn income are salaried work in the service sector, timber industry, and to a minor degree in mining [Bodiroza 2003].

The PDI and the characteristics of the villages are intermingled. The village population participated directly in the program design; their requests were mainly inputs which support traditional extensive agricultural practices. The program introduced no important technological innovations. A village characterization after the PDI implementation must consider both village and PDI aspects together.

The change in land tenure rights by entitlement was a significant PDI-component. The administrative process of clarifying land tenure is complex and highly technical. It includes comprehensive land survey information, community interviews, and submission of land claims. Clarifying land tenure also often requires resolving a number of different superposition demands, i.e., various claimants to the same land. GOB financed the process, including surveys, attorneys, and other experts who advised and guided villages until titles were issued. The same process was performed additionally for 47 individual property owners who had granted easements along the right of way [GasOriente Boliviano (2003)]. The significance of this component is due to the fact that in the Chiquitano Region, as well as in all of Bolivia, the land area with clear property rights is very small; there are a great number of spatial superposition problems[33]. In 2002, only 21.94% (141 638.63km²) of the total area of land with unclear property rights (645 537.46 km²)[34] had already been clarified [INRA 2002].

Because the investment costs are relatively low and no sophisticated technologies are needed, the insecure land tenure in developing countries can promote deforestation [Bohn & Deacon 2000]. Forest clearing can offer more secure property and usufruct rights, which provide occupants an improved ability to demand future land rents [Angelsen 1996], [Anderson and Hill 1990]. Analysing several studies, [Kaimowitz & Angelsen 1998] states that deforestation

33 The demanded land area in the region is in most cases, larger than the existing area [Columba 2002].
34 Total area of Bolivia: 1 098 581 km².

in Latin America tends to be lower in areas with high land tenure security. Therefore, securing land rights in the research area will probably have a positive effect on forest conservation. In 2002 the property rights were conferred to the villages. An evaluation was not possible, because

these are effects which will be observed in the long-term future. Further research should determine the positive or negative effects on forest. In contrast to the land entitlement component, the component (a) of the PDI provided financial assistance for forest clearing. At least 323ha of former natural vegetation were incorporated into agricultural uses in the whole area of indirect influence; 155ha of this area are localized in the research area [Salmón *et al.* 2002].

3.1.3.1 Case studies

The villages Ramada and San Juan de Chiquitos were chosen to perform case studies. San Juan de Chiquitos has a total of 45 households, whereas Ramada comprises 15.

3.1.3.1.1 Relation between gas pipeline and motivation to move to the village

There is no migration associated with the gas pipeline construction or the PDI. After the construction, only one new household permanently settled in San Juan de Chiquitos. Most important reasons for moving to the villages are: (a) work at the sawmill located in San Juan the Chiquitos and (b) family ties with people that have already lived there.

Table 17. Origin of male households' heads

Born in the village	Ramada N=13	San Juan de Chiquitos N=28
	Number	Number
Yes	8	16
No	5	12

3.1.3.1.2 Household size and personal characteristics of male households' heads

In the research area, the household size varies from 1 to 10 persons, with an average of 5.22 persons. The average age of male household heads is 44.19 years, with considerable variation between villages (Table 17). Most household heads are literate. The maximum number of years attending formal education is 10 in Ramada, whereas in San Juan de Chiquitos this number increases to 12, meaning that these persons completed the Bolivian high school (see Appendix III).

Table 18. Household size and age structure

Characteristic	Ramada N=13		San Juan de Chiquitos N=28	
	Mean	Standard deviation	Mean	Standard deviation
Household size	5.08	3.17	5.36	2.31
Age of male household head	49.00	14.36	39.37	17.24
Years of formal education	5.31	2.75	5.83	3.47

3.1.3.1.3 Labor resource

The majority of the male household heads in both villages are engaged in agriculture (84.61% in Ramada and 85.71% in San Juan de Chiquitos). The most important agricultural activities are the clearance and burning of forest, soil preparation, and planting. Because households practice agriculture principally for own consumption, the involvement in off-farm employment is important for cash generation. However, the off-farm job market is limited. Offers are mainly restricted to activities which are associated to forest degradation, like selective logging and cattle raising. Off-farm employment is rarely offered in a continuous (12 months/year) way. The share of male household heads involved in off-farm employment in Ramada is lower (30.76%) than in San Juan de Chiquitos (85.71%).

Table 19. Involvement in off-farm employment

Type of employment	Ramada N=4		San Juan de Chiquitos N=24	
	Number	Percent	Number	Percent
Petty traders	0	0	4	16.66
Teacher	1	25.00	1	4.16
Cattle raising daily labor	3	75.00	1	4.16
Sawmill laborer	0	0	9	37.5
Lumberjack	0	0	4	16.66
Others	0	0	5	20.83

3.1.3.1.4 Farm characteristics and issues concerning the gas pipeline compensation program

Shifting cultivation, mixed cropping, and phased planting are practiced using manual tools. The most important crops are maize and rice, which are followed in the second year by yucca and beans. Each farmer has an individual plot, which is located side by side with other farmers' plots. This plot arrangement in blocks began with the implementation of the PDI; before this program the location of the individual plot was chosen arbitrarily. Such blocks are performed with the purpose of establishing common pasturelands, after 2 or 3 years of cultivating crops. The expansion of pastures was already practiced before the PDI implementation, although on a minor scale, because fallows lands were more practiced. Pasture enlargement occurs at the expense of forest. This trend was strengthened by the PDI through agricultural extension activities and especially with the endowment of credits for agricultural inputs that farmers could not afford, like cattle and wire.

The PDI contributed, at least in a temporary fashion, to the improvement of the well-being of village inhabitants. The program was the most unique aid received from any private or public institution between the years 2000 and 2002, and possibly the only aid in many years. The behavior of farmers that designed the PDI projects is well described by [Angelsen & Kaimowitz 2001b]: 399: "Consider the typical situation of a Latin American farmer who produces cattle, crops and forest products. Cattle offer less income per hectare but the highest rate of return on capital and labor. Capital constraints generally limit farmers' ability to expand their cattle herds. If a new crop technology boosts overall farm income and livestock are still farmers' most profitable alternative, the farmers may use their higher incomes from crop production to buy more cattle. Thus pasture may expand, rather than the cropping system that experienced the technological progress".

No new crop technology was introduced. Instead, the farmers requested cattle. Thus, agricultural extension activities strengthened the tendency of pasture expansion. Improved seeds and manual tools were provided to some degree to farmers that either did not receive wire or who already owned tools.

Comparing the number of households involved in crop cultivation before (1999) and after PDI implementation (2002), an increase is shown in San Juan de Chiquitos (from 67.85% to

85.71%) (see Appendix IV). In Ramada, however, all households were involved in crop cultivation in both years (Fig. 18). However, a larger increment in the mean cultivated area per household took place in Ramada (0.22ha) than in San Juan de Chiquitos (0.15ha). With the financial support of the PDI, a total of 38ha in Ramada and 32ha in San Juan de Chiquitos of forest were cleared. Figs. 19 and 20 show areas cleared with the financial support of PDI, as well as the current land use in San Juan de Chiquitos and Ramada.

Figure 18. Comparison between cultivated area per household before and after PDI implementation (ha)

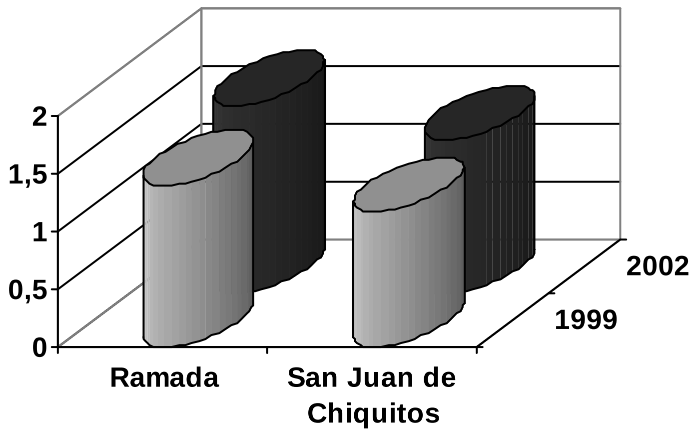
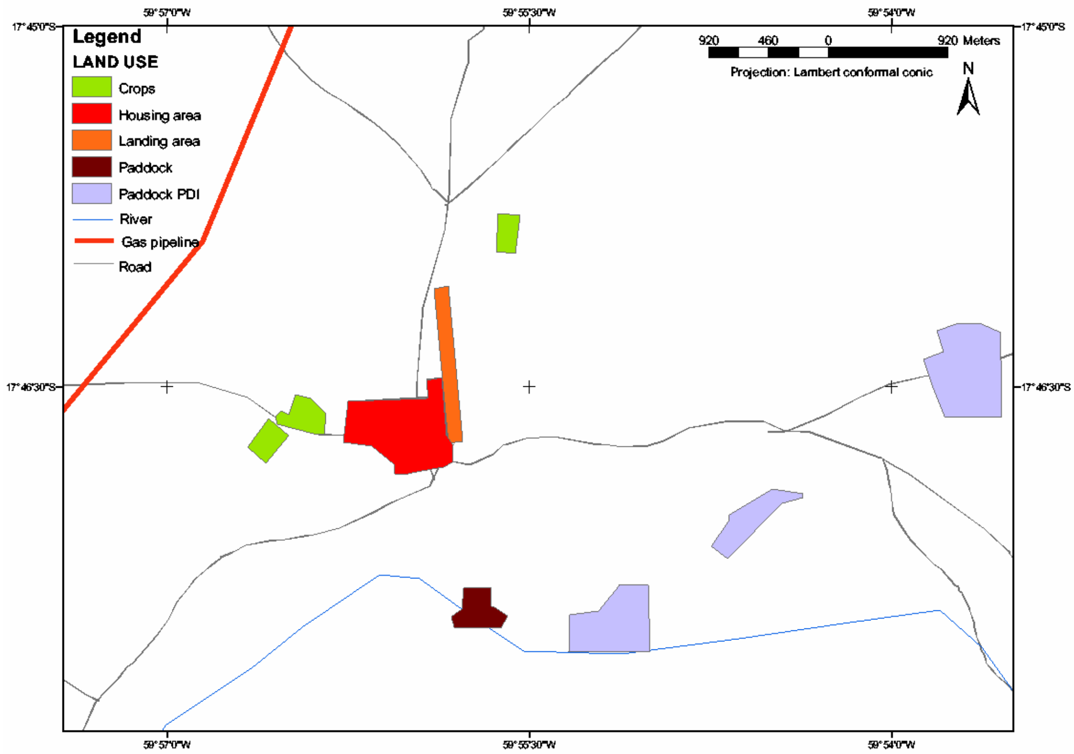
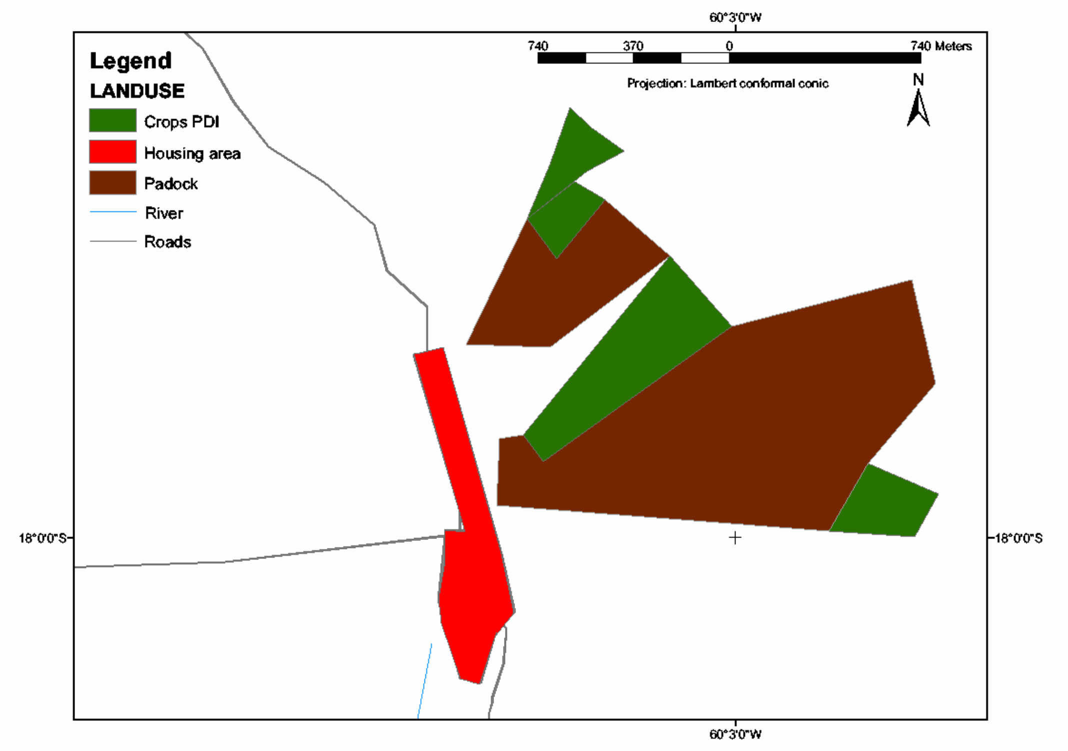


Figure 19. San Juan de Chiquitos diagram (2002)



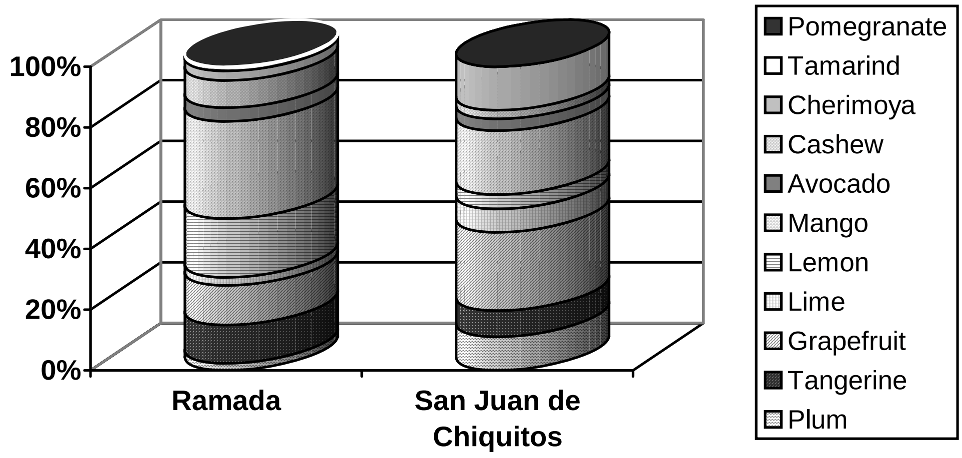
Source: Updated from Bodiroza 2003.

Figure 20. Ramada diagram (2002)



Some households have fruit trees. The cultivated species are: *Prunus americana* (plum), *Citrus reticulata* (tangerine), *Citrus paradisi* (grapefruit), *Citrus aurantifolia* (lime), *Citrus limon* (lemon), *Mangifera spp.* (mango), *Persea americana* (avocado), *Anacardium occidentale* (cashew), *Annona cherimola* (cherimoya), *Tamarindus indica* L. (tamarind), and *Punica granatum* (pomegranate). Fig. 21 shows the share of fruit trees per village in the interviewed households.

Figure 21. Total of fruit trees per village



Regarding livestock, many households are in possession of animals. In order of importance, households tend to own poultry, donkeys, pigs, cattle, and horses (see Fig. 22 and Appendix V). Livestock holding supplies household consumption and other needs. Chickens are occasionally sold within the neighborhood for immediate cash generation. Cattle are mostly used as a "savings book" and are accordingly sold as needed. Table 20 shows the mean number of livestock owned per household in each village.

Figure 22. Households per village owning livestock

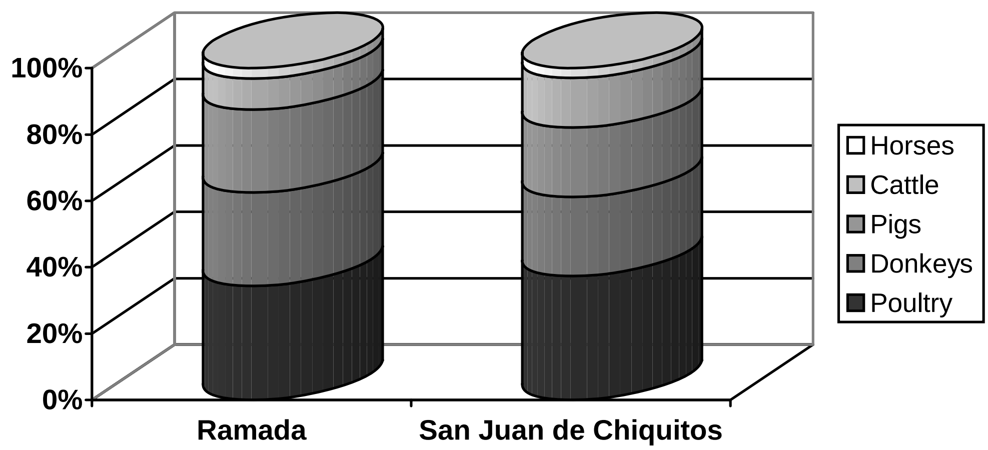


Table 20. Livestock owned per household

Livestock type	Ramada N=13		San Juan de Chiquitos N=28	
	Mean	Standard deviation	Mean	Standard deviation
Cattle	1.62	5.53	5.07	9.21
Poultry	21.46	13.90	17.36	16.07
Pigs	3.15	3.24	2.25	4.54
Horses	0.62	2.22	0.21	0.96
Donkeys	1.85	1.86	1.54	3.00

Cattle raising is practiced in an extensive manner. Paddocks are mainly used for grazing of cows in prenatal and postnatal periods. The total number of cattle in Ramada and San Juan de Chiquitos before PDI implementation corresponded to 21 and 142 animals, respectively. Most households do not own cattle (64.3% in San Juan de Chiquitos and 84.6% in Ramada).

Concerning the distance roamed by cattle for browsing, farmers' opinions vary quite considerably: their answers range from 1 to 10km, with an average of 5km (see AppendixVI). Based on this, the mean distance roamed by cattle is 3km in Ramada, while in San Juan de Chiquitos it is 6.20km.

The PDI cattle component included cattle provisions in the form of rotary credits, vaccines, and medications, as well as wire and pasture seeds (*Panicum maximum*) for establishment of paddocks. The PDI cattle were not assigned to single households. Interested male household heads were organized into communal workgroups to hold the PDI cattle.

Until 2002, the number of cattle increased through the PDI 73.94% (105 animals) in San Juan de Chiquitos. The most important increase 514.28% (108 animals), however, took place in Ramada. The PDI also included rotary[35] credits in other domestic animals which were given to individual households instead of communal workgroups. Households could choose between poultry or pigs. Table 21 shows increments in both. Most households preferred to receive poultry because, compared with pigs, these are easier to hold as and are relatively inexpensive. Poultry increased in both San Juan de Chiquitos and Ramada, 59.70% and 50.63%, respectively. The most important increments in pigs correspond to Ramada, with 42.25%; in San Juan de Chiquitos the amount of pigs held increased only 12.50%.

[35] Note: The status of other benefits provided by the PDI at the moment of survey performing was the following:
- The handicrafts project was not implemented at the moment of interviewing.
- One person was trained to be an environmental promoter in Ramada.

Table 21. Changes in livestock per village: before and after PDI

Characteristic	Ramada			San Juan de Chiquitos		
	Cattle	Pigs	Poultry	Cattle	Pigs	Poultry
Number of benefiting households	15	10	8	17	3	20
Number of animals provided by PDI	54	30	176	54	9	420
Number offspring from PDI animals up to 2002	54	0	96	51	0	300
Total PDI animals up to 2002	**108**	**30**	**272**	**105**	**9**	**720**
Number of animals without PDI	21	41	279	142	63	486
Total village animals in 2002	129	71	551	247	72	1206

Source: Salmón *et al.* 2002 and Author.

3.1.3.1.5 Hunting

Hunting is widespread: 76.92% of male household heads in Ramada and 89.28% in San Juan de Chiquitos hunt at least once a month. The frequency of hunting varies from 1 to 30 times per month (t/m). The mean hunting frequency is 4.35 t/m, (see Table 22 and Appendix VII). Compared with Ramada, the average distance walked by hunters in San Juan de Chiquitos increases twofold (see Table 22 and Appendix VIII).

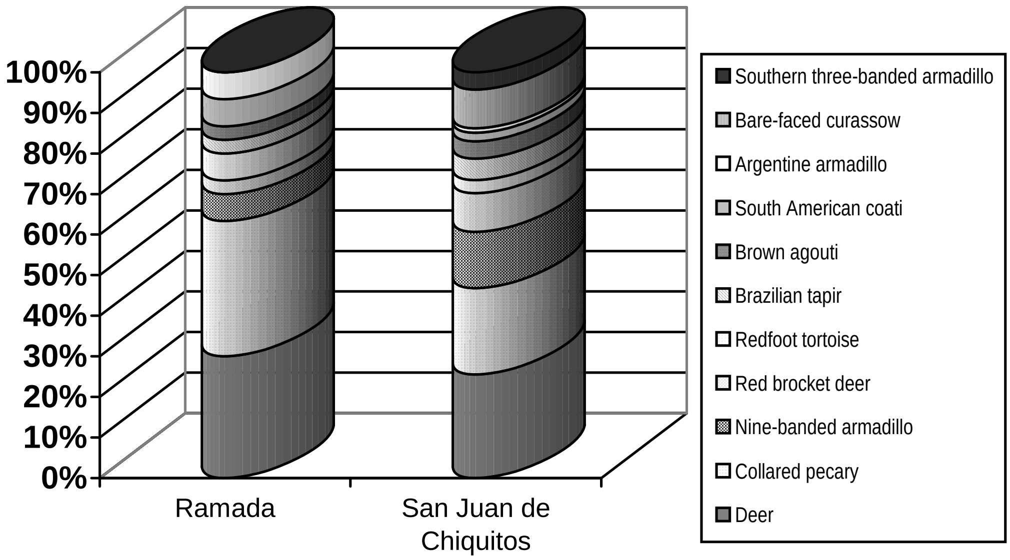
Regarding the use of the right of way for hunting, 20% of Ramada hunters (2 persons) and 40% of San Juan de Chiquitos hunters (10 persons) said they use the right of way to penetrate into the forest during hunting activities. This difference can be related to the distances between the villages and the right of way. The shortest route from San Juan de Chiquitos is 2km, while Ramada is located at 11km from the right of way.

Table 22. Characteristics of hunting

Characteristic	Ramada N=10		San Juan de Chiquitos N=25	
	Mean	Standard deviation	Mean	Standard deviation
Monthly frequency of hunting	5.30	8.83	3.98	5.67
Km walked for hunting	8.10	4,72	15.48	13,42

Considering the villages altogether, 89% of the interviewed hunters usually hunt Mammalia, 7% hunt Aves, and 4% hunt Reptilia. More details regarding the species per village can be seen in Fig. 24. Interviewed hunters commonly hunt a total of 9 and 11 species in Ramada and San Juan de Chiquitos, respectively. In both villages, preferred species are *Mazama gouazoubira* (deer), *Tayassu tajacu* (collared peccary)[36], and *Dasypus novemcinctus* (nine-banded armadillo). Other species hunted in both villages are *Mazama americana* (red brocket deer), *Chelonoidis carbonaria* (redfoot tortoise), *Tapirus terrestris* (Brazilian tapir or South American tapir), *Dasyprocta variegata* (brown agouti), *Nasua Nasua* (South American coati) *Euphractus sexcinctus* (Argentine armadillo). The species *Crax fasciolata* (bare-faced curassow) and *Tolypeutes matacus* (Southern three-banded armadillo) are hunted only in San Juan de Chiquitos.

Figure 23. Game species

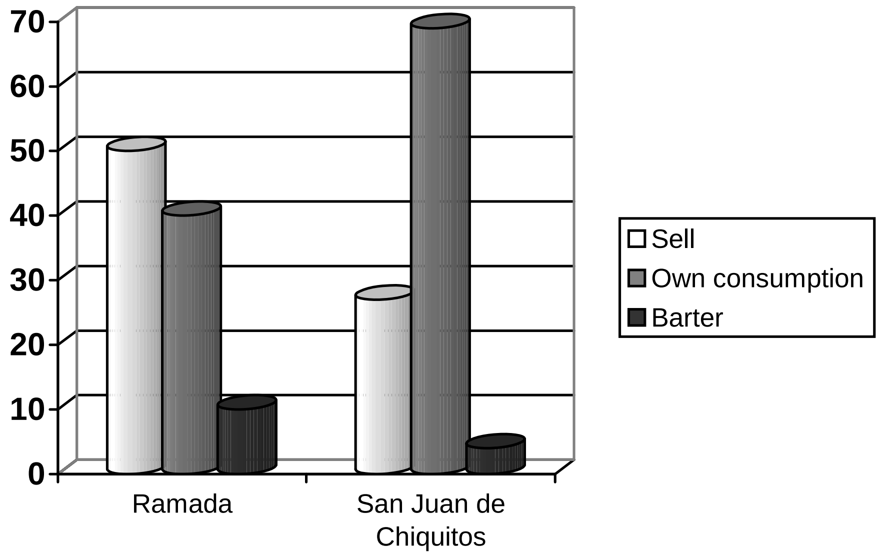


The interviewed hunters generally hunt animals in areas where these go for feeding, i.e., outcrops of natural saltpeter (80% in Ramada and 68.20% San Juan de Chiquitos, as well as areas of fruit trees (60% in Ramada and 31.80% San Juan de Chiquitos). Closed forest is also used because it provides cover, thus facilitating hunting (50.0% in Ramada and 22.70% San Juan de Chiquitos). Water sources are more used in San Juan de Chiquitos (59.10%) than in Ramada and (10%). A lower number of hunters hunt animals in prairies (9.10%); this occurs exclusively in San Juan de Chiquitos.

[36] *Tayassu tajacu* is listed in the Appendix II of CITES (Convention on International Trade in Endangered Species of Wild Fauna And Flora), likewise is categorized as “vulnerable” in the IUCN Red List of Threatened Species [MHNNK 2002] (A taxon is considered Vulnerable when it is not Critically Endangered or Endangered but is facing a high risk of extinction in the wild in the medium-term future [IUCN 1994]).

Concerning the use given to game, Fig. 25 shows that game tends to be more tradable in Ramada than in San Juan de Chiquitos. In both villages barter and sale of game take place exclusively at village level within the neighborhood. In Ramada 50% of the interviewed households sell at least part of the game and 10% barter it. In San Juan de Chiquitos the equivalent values correspond to 27% and 4%, respectively. Most interviewed households in San Juan de Chiquitos, i.e., 69%, use game for own consumption; while in Ramada this share corresponds to 40%.

Figure 24. Use given to game



3.1.3.1.6 Fuel wood

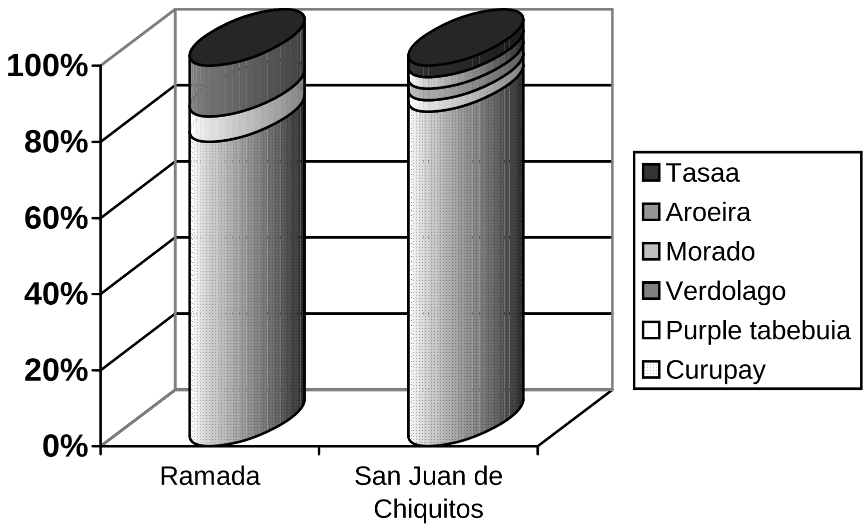
All households collect fuel wood for cooking. Some households in San Juan de Chiquitos use gas sporadically (in the rainy season or in the morning to prepare breakfast). The mean weekly consumption of fuel wood is 0.97m³ per household, i.e., 3.88 m³ per month. Fuel wood is collected close to villages at a maximum distance of 2km. The mean distance roamed is 1.16 km (see Table 23 and Appendix IX). After [Montes de Oca 1997] the Bolivian consumption of fuel wood reaches 1 500 000 MT annually; more detailed data concerning household level were not available.

Table 23. Characteristics of fuel wood collection

Characteristic	Ramada N=12		San Juan de Chiquitos N=27	
	Mean	Standard deviation	Mean	Standard deviation
Mean consumption of firewood (m^3)	1.14	0.62	0.89	0.95
Mean distance roamed	1.30	0.64	1.09	0.44

There is no fuel wood market; all households collect fuel wood for own consumption and according to their needs. As can be seen in Fig. 26, *Anadenanthera colubrine* (Curupay, Vilca) is the most important plant species used as fuel wood. 88% and 80% of interviewed households generally use this species in San Juan de Chiquitos and Ramada, respectively. The interviewed households in both villages use *Tabebuia impetiginosa* (ipe, purple tabebuia) to a lesser degree, with 3% in San Juan de Chiquitos and 7% in Ramada. Other plant species, such as *Calycophyllum multiflorum* (verdolago) (13%) in Ramada, or *Machaerium scleroxylon* (Morado), *Schinopsis brasiliensis Engl* (Aroeira), and *Acosmium cardenasii* (Tasaa) (3% each) in San Juan de Chiquitos are used only in one village.

Figure 25. Fuel wood species



3.1.3.1.7 Selective logging

Timber extraction and commercialization is illegal in Bolivia[37], but field observations demonstrated that selective logging is practiced in the research area without official permission. It is possible, due to the illegal nature of logging, that most interviewed male household heads that are actually engaged in logging activities did not admit it. Three and two of the interviewed male household heads; in Ramada and San Juan de Chiquitos, respectively, admitted their engagement in timber extraction and commercialization. This enabled the collection of at least partial information about logging in the research area.

The following species are logged: *Tabebuia impetiginosa* (Ipe, purple tabebuia), *Cedrala fissilis* (cedar), *Pterogyne nitens* (amendoim), *Aspidosperma cylindrocarpon* (peroba rosa, Bolivian pear), *Schinopsis brasiliensis* Engl (aroeira), *Cordia alliodora* (salmwood), *Astronium urundeuva* (cuchi), *Amburana cearensis* (soriocó), *Calycophyllum multiflorum* (verdolago), and *Machaerium scleroxylum* (morado). During 2002 (January-May), at least 130 and 1025 trees were logged in Ramada and San Juan de Chiquitos, respectively. This is equivalent to a rate of 26 and 205 trees per month. The dbh harvest limit applied in Ramada varies between 20 and 60 cm, while in San Juan de Chiquitos this value oscillates between 30 and 40 cm.

Regarding the use of the right of way for logging, 21.42% (6) of the total interviewed male household heads in San Juan de Chiquitos admitted using the right of way to penetrate into the forest to perform logging activities. Regarding Ramada, in the nearest access to the right of way from this village there is almost no forest with profitable timber available (see sections 3.2.1.6.1 and 3.2.3.2.4). Therefore, in Ramada the right of way is not used for logging activities. Table 24 shows a summary of all villages and gas pipeline features.

[37] Article number 42 [Ley Forestal 1996]

Table 24. Overview of villages and gas pipeline features

Endogenous aspects of villages	Gas pipeline as exogenous factor	
	Village level compensation program aspects	**Right of way**
Farm characteristics Shifting cultivation Slash & burn Mixed cropping Non-irrigation Non-fertilizer Extensive cattle raising Most households do not own cattle (San Juan de Chiquitos 64.3%, Ramada 84.6%) Some pastures 9-11 fruit trees species cultivated	Received credits once for: (a) Expansion of crops and pastures: at least 38ha (Ramada) and 32ha (San Juan de Chiquitos) of cleared forest (b) Agricultural inputs: • Cattle: Increase of village's cattle 514.28% (Ramada), 73.94% (San Juan de Chiquitos) • Wire for establishment of large pasture blocks • Manual tools • Improved seeds Strengthening the measure of avoid fallow vegetation after crops by establishment of pastures No introduction of technological change	Without evident influence
Fuel wood 100% households use fuel wood for cooking Consumption: 1.03m³ / household/week 3 -5 trees species used (84% *Anadenanthera colubrine*) Mean collection distance: 1.16km	Without evident influence	Without evident influence
Commercialization of agricultural production More than 50% is used for own household consumption Local markets	Construction of store center for agricultural products in nearest town (San José) Grant of 2 trucks (for the 4 villages)	Without evident influence
Hunting Chasing average 4.64/month Average distance 10.76Km 9 - 11 animal species	Without evident influence	31% (San Juan de Chiquitos) and 15% Ramada) of hunters use of the right of way to penetrate into the forest
Selective logging 10 trees species	Without evident influence	21.42% in San Juan de Chiquitos use of the right of way for logging activities

3.2 Structure of monitoring and evaluation system

A major aim of nature conservation is the maintenance of ecosystem components over time and over large areas, in order to ensure the protection of all aspects of biodiversity [Bourgeron 2003]. The term biodiversity circumscribes the diversity of landscapes, species, populations, and genes [Stork 1997]. The health of ecosystems, which can be described by conservation status or closeness to natural conditions, are degraded by human activities. The extent of this degradation determines whether viable conditions to support biodiversity exist. This section depicts the M&E system proposed for assessing the conservation status of large ecosystems near natural conditions. The approach uses land cover information improved with quantitative land use data.

The M&E system consists of four components structured as follows:

3.2.1 Final set of conceptual factors and indicators,
3.2.2 Knowledge-based models for spatial evaluation,
3.2.3 Validation of the system and baseline M&E,
3.2.4 Brief M&E protocol

3.2.1 Final set of conceptual factors and indicators

In this section the theoretical description of factors, indicators, and corresponding sub-indicators required to assess the ecosystem conservation status in the influence zone of the gas pipeline (see sections 2.3.1 and 2.5.1.) are introduced.

An indicator is any quantitative or qualitative variable of the forest ecosystem or management system which, measured over time, can help infer the status of a particular criterion. Criteria should convey a simple message which represents an aggregate of one or more data elements with certain established relationships. A given criterion can be deduced from multiple indicators [CIFOR 1999], [IFAD 2005].

3.2.1.1 Conceptual factor 1: Level of agricultural intensification

Shifting cultivation utilizes several times more land per unit of production than permanent agriculture does. Furthermore, shifting cultivation is a widespread activity in the tropics; around 200-300 million farmers are shifting cultivators [Drigo & Marcoux 1999]. Estimations affirm that 10 million ha of tropical rain forest are cleared yearly for shifting cultivation [IFAD *et al.*]. Nevertheless, for the research area and in general for Latin America, pastures are currently the main agent of deforestation [Angelsen & Kaimowitz 2001a]. When the technological level does not change, farmers usually expand the agricultural frontier as a way of augmenting the agricultural yield [Müller & Zeller 2002], [Angelsen & Kaimowitz 2001a].

"Converting forest permanently to a stable, land-intensive, high return form of land use may in many cases be more 'desirable' (potentially for both the people and the environment) than a shifting, low return, technologically static form of land use that expands monotonously with-ever-growing product demand" [Wunder 2003]: 65. To what extent the level of agricultural intensification influences deforestation has been widely investigated and well discussed. Numerous studies have demonstrated both positive and negative effects of technical change on forest clearing. These contradictory results can be explained by the different conditions that exist in every research area, as this can influence the relationship between available technology and deforestation in dissimilar ways [Angelsen & Kaimowitz 2001a].

Concerning Vietnam, Müller & Zeller 2002: 347 found that "higher agricultural productivity on existing land reduced the need for shifting cultivation, thus preserving forest cover while sustaining a much greater population on virtually the same agricultural land area".

The higher the level of agriculture intensification, the lower the land area required for growing crops. The expansion of the agricultural frontier is substituted by technological inputs. The intensification process involves the replacement of land with more labor or more efficient technology. However the analyses of several studies like [Holden 2001], [de Jong 2001], [Ruf 2001], and [Yanggen 2001], enable [Angelsen & Kaimowitz 2001a] to conclude that "New technologies can, in principle, reduce the need for land, but farmers often choose to expand land area". To a large extent this depends on the type of technology involved: "Technological changes that increase yields without significantly altering labor or capital requirements can be expected to increase deforestation" [Angelsen & Kaimowitz 2001a]. The phenomenon *intensification and expansion* occurs due to the fact that farmers frequently profit from the improved productivity and expand land area, especially if forest is abundant and the farming intensification takes place by means of new technologies saving labor. This labor surplus can be invested in clearing more forest for agricultural purposes.

3.2.1.1.1 Indicator 1: Technological level

The type of available technology is a determining factor in evaluating the level of agricultural intensification. The best suitable technologies with regard to forest conservation are those that require high labour inputs [Angelsen & Kaimowitz 2001a], [Cattaneo 2001], [Müller & Zeller 2002].

Investments in irrigation systems, combined with further improvements in infrastructure, have been shown to cause a positive effect on the intensification of agriculture in Central Vietnam [Müller & Zeller 2002]; in addition [Maertens *et al.* 2002] indicates that the enhanced irrigation infrastructure in Indonesia reduced the land area under cultivation in Central Sulawesi. [Maertens *et al.* 2002] compare their results with [Deininger & Minten 1999] and [Shively and Martinez 2001], who determined in Mexico and Philippines respectively that irrigation policies also served to diminish deforestation.

Concerning agrochemical inputs, the effect on farming intensification is still not defined. In South Cameroon, an increase in the use of chemical inputs reduced deforestation [Mertens 2000]. On the contrary, in some Latin American contexts an increase in fertilizer prices, which implies a drop in the use of fertilizers, could reduce deforestation. In Southern Africa, higher fertilizer prices, increased deforestation in some cases, while in other cases fertilizer prices showed little effect [Kaimowitz & Angelsen 1998].

New crop varieties that increase yields without significantly altering the demand for labor or capital enlarges the amount of forest cleared by each farmer [Kaimowitz & Angelsen 1998].

Due to the ambiguous role of agricultural technology with regard to deforestation and to the evaluation of the available technological level, four sub-indicators are proposed. In the model it is assumed that these sub-indicators lead to increased agricultural intensification. The data are obtained from household interviews (see section 2.4.1.1).

In the research area, there is a general tendency to practice agriculture in an extensive manner because the available technology is limited to manual tools and some mechanic saws. On the other hand, the land input is the most abundant, the capital input the scarcest, and the economic profitability is also low. Furthermore, there are some intensive cattle farms in other areas of the Chiquitania region with similar low yields, because the market cannot afford to pay for higher quality meat [Columba 2002]. No substantial investments are expected that would improve the technological level of farming.

The sub-indicators of the technological level of agriculture are:

- Percentage of households using improved seeds
- Percentage of households using agrochemicals
- Area under irrigation
- Type of tools utilized

3.2.1.1.2 Indicator 2: Percentage of households not practicing fallow

The importance of the fallow period for shifting cultivation lies in the cost-free and effortless regeneration of soil productivity during this period, especially when the fallow consists of forest or bush vegetation. “Forest and bush vegetations reduce leaching and store nutrients, which are made available to crops to a significant degree by fire clearance and the resulting temporary increase of the pH” [Ruthenberg 1980]: 45.

After longer periods of crops an area increasingly loses yield, particularly if agricultural inputs such as fertilization or management e.g. long fallows do not occur [Dvorak 1992]. Concerning the introduction of innovations in shifting cultivation systems “(…) All measures that increase the cropped area or the yield per hectare shorten the fallow period or make the regrowth of a fallow vegetation more difficult; and the fertility of the soil is closely related to its content of nutrients and organic matter, and thus to the length of the fallow period and the vigor of the fallow vegetation” [Ruthenberg 1980]: 60.

In the research area, the practice of establishing pastures after one to three years of food crops is highly disseminated and has been stressed through the PDI. Thereby, instead of leaving fallow lands, which can be used again after a “pause-period” for food crops, the farmers opt to plant pastures; as a result, the agricultural frontier expands more quickly because new forest areas are repeatedly changed into crops and then into pastures. The soil productivity of such pastures falls and their quality declines in later years.

[Angelsen & Kaimowitz 2001b] quoting [Vosti *et al.* 2001] pointed that similar cases are typical in the contexts of Latin American forests. In the short term, a win-lose scenario takes place since the farmer's profit increases through the expansion of new pastures. But in the long term that pattern may describe a lose-lose scenario: when forest becomes smaller, the traditional cattle system deteriorates; consequently the farmer's profit decreases and deforestation increases[38].

3.2.1.1.3 Indicator 3: Mean land area used per household

There is a general agreement confirming the key role that both types of agricultural expansion play in forest clearing [Kaimowitz & Angelsen 1998], [Müller & Zeller 2002]. The expansion of cultivated pastures is a main source of deforestation in Latin America [Kaimowitz & Angelsen 1998] as well as in the research area. Since the research villages are surrounded by forest, the enlargement of the occupied area, either for crops, cultivated pastures, or housing, will be gained at the expenses of forest. After one to three years of subsistence crops, there is a generalized tendency to establish pastures. Additionally, the cattle will keep increasing; an increment in the total area of pastures is to be expected.

The area occupied by villages is a direct indicator to determine the level of change in land use, as well as a key variable regarding the level of agricultural intensification. Intensification is defined as a higher input use (or output) per hectare of cultivated land [Angelsen & Kaimowitz 2001a]. It is assumed in the model that an increase in the total area occupied per household will lead to a decrease with regard to agricultural intensification. The following sub-indicators are proposed:

- Cultivated area of pastures per interviewed household
- Housing and crop areas per inhabited household[39]

3.2.1.2 Conceptual factor 2: Level of agricultural commercialization

In contexts where agriculture takes place in an extensive manner (i.e. low level of agricultural intensification exists) and land is abundant, the area required for production is related to the

[38] For details and policy implications, see [Angelsen & Kaimowitz 2001b], [Vosti et al. 2001] and [Kaimowitz & Angelsen 2001].

[39] To obtain the housing and crops areas: Total area of villages (achieved by means of GIS analyse of the supervised classification of the current Landsat scenes) minus (-) the amount of cultivated pastures areas.

demand of product. With subsistence-oriented production, the area required for cultivation will be smaller than the area needed for a commercial-oriented production. Extensive systems can expand monotonously with ever-growing product demand [Wunder 2003]. Thus, the level of commercialization of production influences the farming pressure on forest.

3.2.1.2.1 Indicator 4: Proportion of commercialized farm produce

The destination of the agricultural output of a village informs us about its degree of market development. In this context, [Ruthenberg 1980] classifies farms into three groups based on the destination of the agricultural output:

1. Subsistence farming, if there is practically no sale of crop and animal products.
2. Partly commercialized farming, if more than 50% of the value of the produce is for home consumption, and
3. Commercialized farming, if more than 50% of the produce is for selling.

To evaluate the level of commercialization of farm produce the following sub-indicators should be considered:

- Percentage of commercialized crop production per household
- Percentage of commercialized cattle production per household

3.2.1.3 Conceptual factor 3: Incentives for expansion of tree logging and agricultural production

The growth in areas dedicated to crops and pasture (the spatial expansion of agriculture) is in many countries "the only factor that has any significance in terms of alternative uses of deforested land. Agriculture is the big land-use competitor of forest. This produces a somewhat uneasy implication: most of what is good news for agriculture tends to be bad news for forest, and vice versa. And policies that are biased against agriculture may, unintentionally, become forest-conserving" [Wunder 2003]: 342. The agricultural expansion into previously uncultivated areas increases agricultural production at the expense of forest cover. The expansion of agricultural land is one of the key processes of land use change and generally occurs at an extensive and constant technological level [Müller & Zeller 2002]. The technology available in the research area is of low level and the existing capital is in short supply. For these reasons, the region is still dominated by forests and extensive farming is practiced.

As reported in the literature ([Kaimowitz & Angelsen 1998], [Maertens *et al.* 2002], [Mertens 2000], [Müller & Zeller 2002], [Pacheco 1998], [Pfaff 1997], [Ruthenberg 1980]), a large number of exogenous variables can influence deforestation. In the research area these variables could be, at macro level: control of prices and lands policies (e.g. agrarian reform); and at micro level: credit availability, accessibility, and irrigation facilities. During field observations, two principal aspects were identified: (a) quality of roads and (b) credit availability. In other regions of the Bolivian low lands, the small farmers profited from land allocations and easy access to markets through the construction of roads [Pacheco 1998].

3.2.1.3.1 Indicator 5: Average traveling speed on all-year road

Deforestation tends to be greater when forested areas become easily accessible. [Kaimowitz & Angelsen 1998] analyzed 146 economic models of tropical deforestation and concluded with respect to agriculture and its level of commercialization, that roads appear to have a stronger impact on the regions with good soils and dominated by commercial agriculture than on regions inhabited mainly by small farmers that practice slash and burn cultivation on poorer soils. Nevertheless, subsistence agriculture may become more commercial, and this aspect should be considered in monitoring activities. However, in the research area logging is currently a more important financial source than agriculture.

Better quality roads reduce the transport costs: by improving accessibility to markets, produce trade is more profitable. The access to roads and the distance to output markets determine the transaction costs in relation to marketing produce [Maertens *et al.* 2002]. The quality of roads directly influences the transport costs. The better roads are, the lower the costs in: gasoline, time, maintenance of means of transportation, etc. Lower transport costs improve accessibility, resulting in more profitable forest logging and agriculture harvest [Angelsen & Kaimowitz 2001a], [Angelsen & Kaimowitz 1999], [Cattaneo 2001], [Kaimowitz & Angelsen 1998].

Several studies have been carried out in different countries analyzing the effect of roads on deforestation. Some examples of the numerous proxy variables that have been used are: travel time to market [Maertens *et al.* 2002], distance and travel time to all-year road [Müller & Zeller 2002], km from village to nearest town in straight line [Godoy *et al.* 2001], road density [Pfaff 1997], pixel shortest distance to the nearest road [de Koning *et al.* 1998], [Mertens & Lambin 1997]. In developing areas the road network conditions are extremely different from country to country an often within in the same country from region to region. The road network conditions directly influence the possible travel speed on a given surface, and it is certainly easier (and therefore faster) to travel on asphalt highways than on stone pavement roads or dirt roads. There is a direct relationship between possible travel speed and road quality. The average travel speed on all-year roads is proposed as a proxy variable for the measurement of road quality and consequently of accessibility.

3.2.1.3.2 Indicator 6: Provision of financial incentives by Gas Company for the expansion of the agricultural lands

[Angelsen & Kaimowitz 1999] and [Kaimowitz & Angelsen 1998] found a correlation between availability of farm credit (mainly for keeping livestock) and the deforestation in Latin American tropical regions. In the research area the credit availability of villages is extremely limited. During 1950's and 1960's a state bank (Banco Agrícola de Bolivia) provided a considerable amount of credits to enhance the agricultural expansion. In this case 42.2% of the total credits given in all of Bolivia were destined for the Department of Santa Cruz ($ US 9.2 millions). However, the major beneficiaries of those programs were the large agricultural producers, since the bank required guaranties that small farmers could not provide [Pacheco 1998]. Villages included in this research were therefore left out from such programs, which in the end benefited only producers near Santa Cruz city. The construction of the gas pipeline in the vicinity of some villages changed this situation through the PDI (see section 3.1.3).

The PDI was a one-time donation [GasOriente Boliviano (2003)] but will have effects in the long-term future, because cattle adapted well to the area and reproduction is quite successful. Evaluation of separated effects of the PDI is not possible; they are combined with village endogenous factors such as extensive cattle management. However, indicators 3 *(Mean land area used per household)* and 16 *(Number of cattle)* help in the indirect evaluation of these PDI-effects. The possibility that GOB gives more credits is unlikely in the future; therefore, this aspect is left out of the evaluation. For verification of that possibility, the corresponding official information's source is GOB.

3.2.1.4 Conceptual factor 4: Land cover

Land cover refers to the (bio-) physical ground cover of the land surface and immediate subsurface [Müller & Zeller 2002]. The actual land cover can be obtained in a consistent manner with a high spatial accuracy and relatively low cost using satellite remote sensing systems and digital data analysis techniques [Kalliany 1999], [Kuhn 1999], [Mücher *et al.* 2000]. Monitoring activities of different landscapes are mainly focused on the assessment of the land cover as a variable, which is often obtained from multispectral remote sensing systems[40] ([Strunz & Güls 1999], [Weiers 1999], [Werner & Kenneweg 1999], and [Ziemke & Güls 1999]). These analyses are based on the capability of those systems to distinguish differences in signal strength as they register the radiation reflected or emitted from the ground or the object of interest [Chuvieco 2000], [Jensen 1996], [Jensen 2000].

The continuous changes in land use and therefore in land cover affect the state of the environment. As many environmental and agricultural studies require up-to-date and reliable information on land cover and land use, monitoring the vegetation by using remotely sensed information has become an important research subject [Geodan 2003], [Jensen 2000]. The land cover map for the monitoring year is obtained from the supervised classification of a multispectral image, providing three land cover classes and two indicators.

3.2.1.4.1 Indicator 7: Deforested areas

This is a key indicator since human activities within forests induce alterations which can produce changes in their characteristics and structure at the landscape-level; the area and distribution of habitat types are included among the alterations [Stork 1997]. For the Chiquitania region, the deforested areas have been already considered as an indicator to assess the impact of land use (see Reichle *et al.* 2002). The incorporation of the main infrastructure map (i.e. roads and gas pipeline) improves the information obtained from multispectral images. Therefore, two sub-indicators should be used:

- Deforested areas (from land cover map)
- Infrastructure (known roads and gas pipeline).

[40] E.g. Landsat Thematic Mapper (TM), Landsat 7 ETM+, NOAA Advanced Very High Resolution Radiometer (AVHRR) and SPOT 4 High Resolution Visible Infrared (HRVIR) and Vegetation sensor, ASTER.

3.2.1.4.2 Indicator 8: Natural vegetation areas

This indicator is essential since the research area is covered predominantly by natural vegetation. The area under natural vegetation is subdivided into two sub-indicators, which are important for further calculations (see sections 3.2.2.2.2 and 3.2.2.2.3):

- Open canopy areas: Vegetation areas with discontinuous canopy, i.e. with frequent openings between the tree crowns with a height of 15-20 m (see in section 1.3.2.2.1, ecoregion Cerrado).
- Closed canopy areas: Vegetation areas with dense canopy. Tree crowns fill or nearly fill the canopy layer so that little or no light reaches the forest floor directly and the trees have a height of 20- 35 m (see in section 1.3.2.2.1, ecoregion Chiquitano Dry Forest).

3.2.1.5 Conceptual factor 5: Population

Population pressure has been defined by [Kaimowitz & Angelsen 1998] as one underlying cause of deforestation. Human actions causing degradation of the vegetation cover are influenced to varying degrees by population dynamics such as population growth and migration. Deforestation rates may enlarge with growing population density because of the increased demand for agricultural land, fuel wood, wood, or other forest products [Angelsen & Kaimowitz 1999], [Drigo & Marcoux 1999].

On the contrary, [Angelsen & Kaimowitz 1999] indicated that the population density should be analyzed within the appropriate context because the evidence that growing population pushes deforestation is weaker than often assumed. [Pfaff 1997] showed that the first settlers going into a region have significantly more impact with regard to deforestation than the same number of people added to a densely populated region. This emphasizes the significance of both the establishment of new colonies and the spatial distribution of population. Population density can generate changes in institutions, labor markets, and/or technology availability, which as indirect effects can cause reduction or an ambivalent pressure on forest [Angelsen & Kaimowitz 1999].

"…Rural population density has a greater effect on deforestation in places with less-developed markets, few off-farm employment opportunities, and more equally distributed landholdings." [Kaimowitz & Angelsen 1998]: 96. The research area has similar characteristics. Only indicators that do not allow ambivalent evaluation are used to evaluate the pressure that is caused directly by the population.

3.2.1.5.1 Indicator 9: Number of inhabited houses

Households are the management unit where decisions about resources and labor are taken. In the research area, many households consist of more than one family. Activities such as fuel wood collection or farming plots are done to satisfy the household's (rather than individual or family) demands. In this sense, including families as units, rather than households that share a common kitchen, will overestimate the utilization of natural resources. Moreover, reliable population data are available in Bolivia only every ten years, when the population census takes place. For monitoring purposes reliable and current data are necessary. Because the research villages are small and reviewable, the total number of inhabited houses per village is an indicator of population that is consistent and simple to collect.

3.2.1.5.2 Indicator 10: Fuel wood consumption per household

Forest exploitation for fuel wood can degrade forest, and the effects of this degradation can be more important than the deforestation itself [Burgess 1993]. In India, for example, the over-exploitation of forest for fuel wood is responsible for a large number of environmental problems [Pandey 2002].

Energy needs are directly proportional to population size [Drigo & Marcoux 1999]. They are affected by the trade value of fuel wood and resource availability. The lower the per capita forest area, the higher the fuel wood extraction per unit area will be [Pandey 2002]. When fuel wood is used for energy needs, migration and population growth play key roles in the amount of fuel wood consumed [Drigo & Marcoux 1999]. "Firewood extraction may affect dry forest negatively but have negligible impacts in wood-abundant moist forest with low population densities" [Wunder 2003]: 70.

Bolivian national statistics from 2001 show that 34.06% of the total households (1 977 665) use fuel wood for cooking; at national level, fuel wood is the second combustible, after gas [Instituto Nacional de Estadística 2002a]. In the urban sector gas is the principal energy source for cooking (86.73%). In rural areas fuel wood is the most important domestic combustible (75.08%). Fuel wood consumption is higher in rural areas because of the poor gas supply services and facilities. At departmental level in Santa Cruz, the data show a similar pattern: gas represents the first energy source for cooking and fuel wood the second. 25.35% of the total households (428,653) in the Department use fuel wood for cooking; of these, 10.98% are located in urban areas (36,739 households) and 76.36% in rural areas (71,904 households) [Instituto Nacional de Estadística 2002b].

In the research area, there exists no fuel wood market; however, since other fuels are not available households depend on the forest for fuel wood. This indicator is interdependent with indicator 9, *Number of inhabited houses*.

3.2.1.5.3 Indicator 11: Potential area of fuel wood collection

For fuel wood collection, most impact on wood resources is focused on the peripheral zone of population centres [Drigo & Marcoux 1999]. People collect fuel wood as close as possible to their homes. The potential area of fuel wood collection is a spatial indicator and was defined by an influence area of 1 km radius from the housing area (see section 3.1.3.1.6).

3.2.1.5.4 Indicator 12: Percentage of manpower with potential employment in logging

Improving off-farm employment opportunities usually reduces pressure on forest, because of the decrease in economic benefits generated in agriculture and logging activities that require clearing of forest [Kaimowitz & Angelsen 1998], [Pandey 2002], [Vosti *et al.* 2001].

In the research area, when male households' heads are employed in activities that deforest or cause forest degradation, they constitute the direct agents of deforestation. Clearance of wild vegetation is the most strenuous activity in shifting cultivation, particularly when farmers have manual tools [Ruthenberg 1980]. If the labor market offered other opportunities to work which require less effort, the farmers would be inclined to do this less strenuous work. Only when an alternative occupation can insure income for the household throughout the whole year [Bodiroza 2003] do the economic activities attached to deforestation not play a role in the household economy.

Consequently, the manpower without continuous employment (i.e. 12 months per year) in non-deforestation or non forest degradation activities is considered a suitable indicator to appraise the central aspect of population pressure. Such data is an overestimation, because not all unemployed manpower is able to practice logging. For that reason, this indicator should be carefully considered.

3.2.1.6 Conceptual factor 6: Logging

Logging in Bolivia is highly selective: the maximum rate corresponds to 5 trees per hectare [Pacheco 1998]. Concerning deforestation, the importance of selective logging needs special discussion because of the following two aspects: First, empirical research is scarce because reliable data are difficult to collect. Second, for each context there are local and regional conditions to be considered. Unmanaged logging causes forest degradation in most cases [Burgess 1993], [Cochrane *et al.* 2002], [Pacheco 1998].

In some regions logging causes direct deforestation, whereas in others has only an indirect effect [Kaimowitz & Angelsen 1998]. According to [Wunder 2003], selective logging is a primary source of forest degradation, the extent of which may depend e.g. on the ecological sensitivity of the area, the extraction technology used, or the number of logged trees. During the extraction process forests are scarred by logging roads, total canopy cover is reduced, and neighboring trees are killed or damaged (e.g. crowns lost, uprooting, bark scarring) [Uhl & Vieira 1989]. Depending on the local conditions, this can affect populations, forest structure, and even generate changes at the landscape-level [Pacheco 1998].

3.2.1.6.1 Indicator 13: Potential area of logging

When illegal and informal logging and trade take place, “The expansion of concession areas is normally not a good indicator in quantifying impacts on forests. The appropriation of control over concessions is a process that is driven by legal, infrastructural, and anticipated market factors and not very closely correlated to actual logged-over areas. (…) Forest areas affected by logging may be a more direct indicator of logging impacts” [Wunder 2003]: 72.

Large compact forest is less accessible than fragmented forest patches, as forest patches have more edges per unit area that are vulnerable to anthropogenic influence, [Kaimowitz & Angelsen 1998], [Mertens & Lambin 1997]. The most accessible forests with profitable timber, i.e. the above defined closed canopy areas located near deforested areas; represent the most likely forest to be exploited. Given that, the potential area of logging is a spatial indicator and was defined by an influence area of 0.5 km radius[41] from the edge of the deforested areas which border closed canopy forest. This was done for a 30 km[42] radius from the most northern village.

3.2.1.6.2 Indicator 14: Number of logged trees monthly

For evaluation of logging impacts at the national level, timber production figures are probably the best available substitute for the expansion of concession areas indicator [Wunder 2003]. However, illegal timber production data are not available at either the national or local levels. The number of trees logged per month gives significant information about the direct logging activity, however provides a minimum level of resource pressure.

This indicator refers to the number of trees logged per village that are used for other purposes than fuel wood, such as timber for sale, construction, furniture making, etc. The indicator can be biased as follows: (a) It does not include other trees killed or damaged during harvesting operations; (b) because some lumberjacks work in an illegal manner, their willingness to give real data about harvested trees will be low; and (c) there may be lumberjacks who take logs from the research area who do not reside in the villages and therefore are not part of the sample. Therefore, it is essential that the evaluation of this indicator is combined with its related indicators (see section 3.2.2.2.4).

3.2.1.6.3 Indicator 15: Main use given for the timber

This indicator is useful to estimate the importance of timber as a marketable good. It is assumed that if selective logging takes place for commercial purposes it will have a higher pressure on forest than if logging occurs only to supply the household needs.

3.2.1.7 Conceptual factor 7: Cattle

Pressure exerted by cattle depends mainly on the vegetation type, the number of cattle in a given area, and the management techniques used. “Seasonal livestock overgrazing is a phenomenon restricted to dry forest” [Wunder 2003]: 70. Through extensive grazing systems the cattle pasture free and because of grazing and trampling, forest degradation is generated in various ways.

[41] based on [Reichle et al. 2002]

[42] Maximum distance as far as the currently land cover map presents deforested areas, which are related to logging activities. For subsequent M&E periods it may be necessary adjust this distance.

Extensive grazing causes more degradation at the habitat level than at the landscape level. Most important impacts are the local extinction of species, the alteration of regeneration and succession of vegetal communities, and changes in ecosystem processes [Stork 1997]. Grazing and trampling enlarge the area of uncovered ground by consuming plant biomass. A large proportion of bare ground can accelerate the overland flow of water and in consequence reduce water percolation. Soil compactness due to trampling also causes alterations in water storage; as a result, water infiltration decreases. Plant biomass reduction diminishes the amount of litter, and the organic matter and soil nutrients decrease correspondingly. Thereafter, reduction in plant productivity and vegetation cover is observed. Finally, increased runoff and soil erosion arise [Belsky & Blumenthal 1997], [Ruthenberg 1980].

At the species level, extensive grazing affects reproduction [Stork 1997]. Grazing and trampling result in alterations of the understory species composition, because selected plants are eaten and consequently an increase in unpalatable plants, as well as a displacement of seeds from other different vegetation communities occurs [Belsky & Blumenthal 1997], [Ruthenberg 1980].

3.2.1.7.1 Indicator 16: Number of browsing cattle

The total number of cattle is an important indicator of the amount of pressure on forest.

3.2.1.7.2 Indicator 17: Potential area of browsing

The impact of grazing and trampling actions also concentrates at the periphery of settlements. The distance from population centres determines the sphere of activity of cattle. According to the field observations, a radius of 5 km, measured from the village edges, can define the potential area of browsing in a given village. The same distance has been used by [NNPCD 2002], [Reichle *et al.* 2002], and [Silori & Mishra 2001].

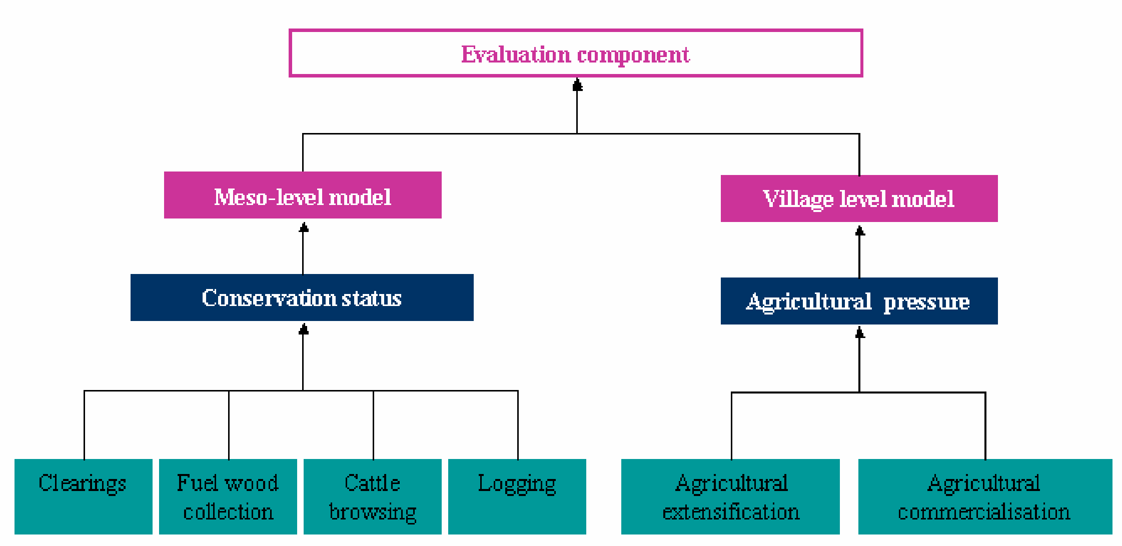
3.2.2 Knowledge-based models for spatial evaluation

Simply collecting indicators does not enable the drawing of conclusions. Indicators are a series of messages that require interpretation and cross evaluation in order to effectively inform about the status of the subject [CIFOR 1999]. For interpretation purposes a structure with defined evaluation criteria is required, to facilitate the production of relevant information from the data. A set of indicators and a set of assumed relations among them that constitute a model of the system of interest can be used to guide implementation of strategies and monitoring, and could allow a greater understanding of the interconnections between actions and outcomes [Beratan *et al.* 2004], [Gallopín 1997].

A criterion is a principle or standard that a thing is judged by. A criterion incorporates the information provided by indicators and constitutes the point where an interpretable assessment crystallizes. Criterion can be treated as reflections of knowledge, where knowledge is the accumulation of related information over a long period of time. It can be viewed as a selective combination of related pieces of information [CIFOR 1999].

Two knowledge-based models were developed to organize the acquired knowledge and to make the spatial evaluation operational, integrating the indicators in relation to their areas of influence (see section 2.5). The models constitute the evaluation component of the M&E system. Fig. 27 shows, on the right side, the Village-level knowledge-based model, which includes all indicators and sub-indicators having influence within villages. The left side of this figure shows the Meso-level knowledge-based model, which includes all indicators and sub-indicators with influence the area outside of villages' edges.

Figure 26. Overview of the evaluation component of the M&E system

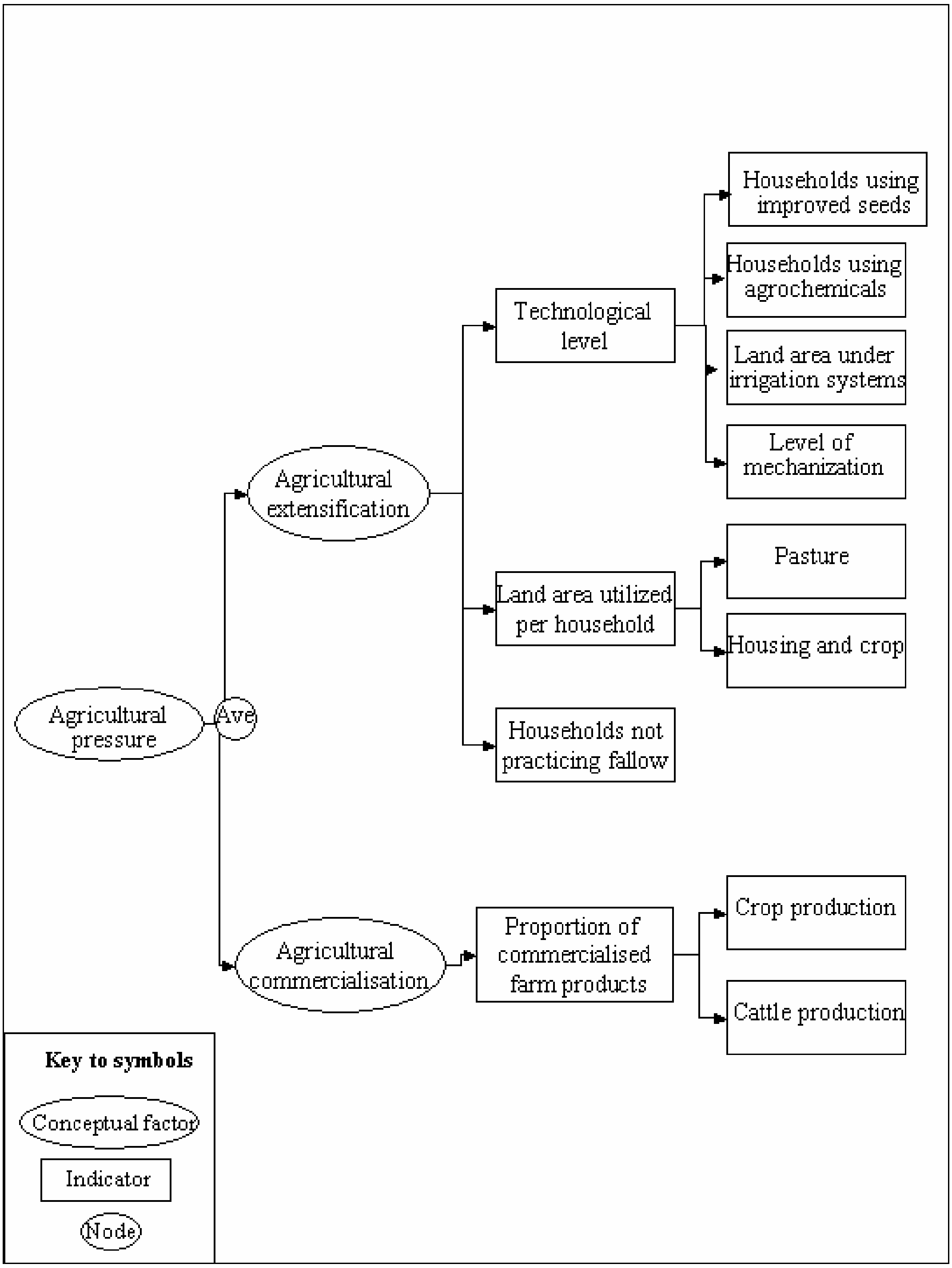


3.2.2.1 Village-level knowledge-based model

The agricultural activities are features that influence at village-level[43]. The evaluation criterion for this knowledge-based model is: **Pressure on forestlands due to extensive agriculture is maintained within acceptable limits.** The theoretical importance of agricultural intensification was depicted in relation to land saving (see section 3.2.1.1); for evaluation purposes the inverse measure “agricultural extensification” is considered. This pressure is determined by (a) level of agricultural extensification and (b) level of commercialization of farm products (see section 3.2.1.2). The indicators and sub-indicators and the relations among them are schematically depicted in Fig. 11. The level of agricultural extensification can be related to the *mean land area utilized per household* and the *proportion of households not practicing fallow,* which are indicators which are associated with an increase in agricultural extensification in the model. The *technological level* is associated with a decrease in agricultural extensification in the model. The *proportion of commercialized farm products* indicator is used to evaluate the level of agricultural commercialization.

[43] Besides free browsing of cattle, see section 3.2.1.7.2

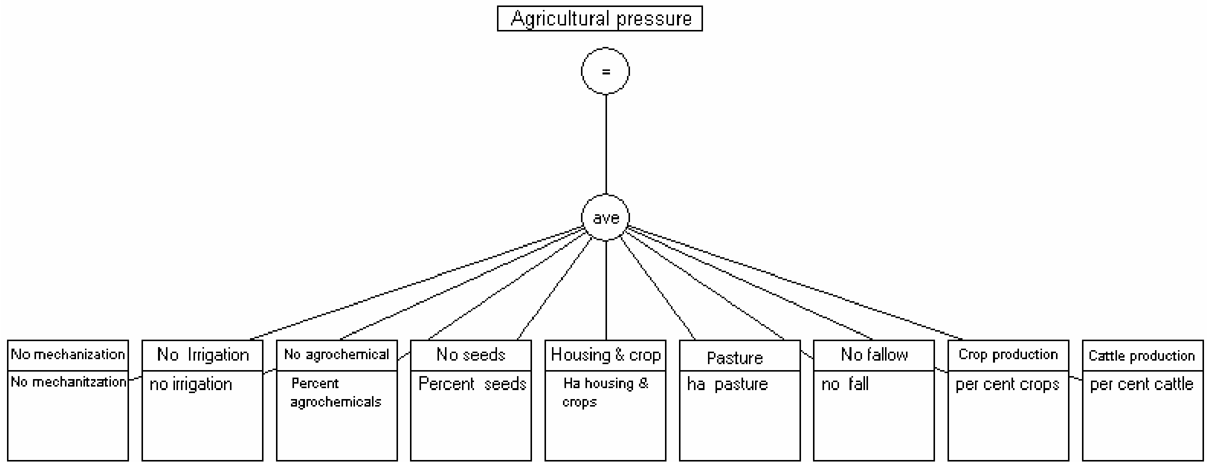
Figure 27. Overview of village–level model structure



3.2.2.1.1 Agricultural pressure network

To make this model operational, one dependency network was developed (see section 2.5.2), which evaluates the level of agricultural pressure on villages surrounding forest. This evaluation takes place by averaging the data links corresponding to the above-specified indicators or sub-indicators (Fig. 28). Except for information about housing and crops area, which is obtained from satellite imagery interpretation and survey data, the data are obtained from the application of a household-level questionnaire. The actual data for a given year are stored in the corresponding vector data layer for each village, which is required to perform the spatial evaluation.

Figure 28. Agricultural pressure dependency network



The respective questions and evaluation arguments for each of these data links follows:

No mechanization data link

How mechanized is the farming system?

Fuzzy argument values[44]:

1: hoe-farming or spade-farming = low (true);

2: farming with ploughs and animal traction = medium

3: farming with ploughs and tractors = high (false)

(Simple data link)[45]

No irrigation data link

How many hectares under irrigation are there?

Fuzzy argument values: 1= low (true); 1000 = high (false)

(Simple data link)[5]

---

[44] After [Ruthenberg 1980]'s classification of cultivation systems according to the implements used for cultivation.

[45] These links are assessed in a negative manner in regard to agricultural pressure.

No agrochemical data link

How many households use agrochemical inputs there?

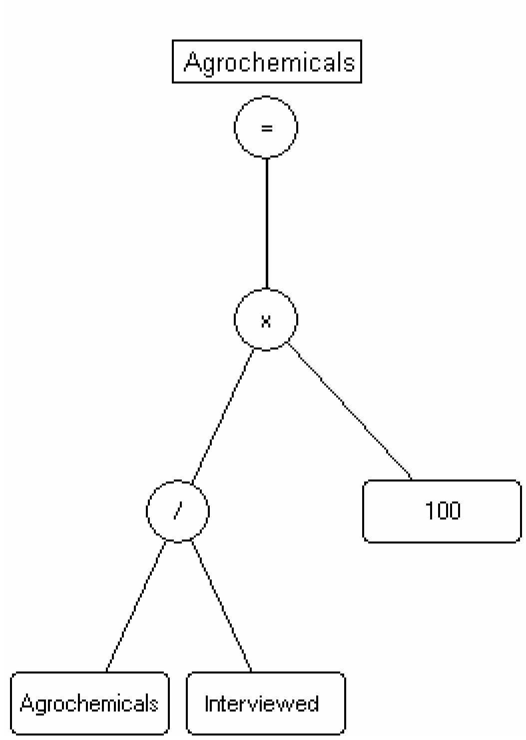
Fuzzy argument values: 1 = low (true); 100 = high (false) [5]

(Calculated data link) The corresponding calculation for this index is:

$$Agrochemicals = \frac{\sum \ households \text{ using } agrochemicals}{\sum \ Interviewed\ households} \times 100$$

Fig. 30 displays the agrochemical inputs calculation. On the left side, Agrochemicals is divided by Interviewed and multiplied by 100 to obtain a percentage.

Figure 29. Calculation for use of agrochemical inputs



Where,

- Agrochemicals represents the total number of households using agrochemical inputs
- Interviewed is the total number of interviewed households
- 100 is a constant value, to obtain a percentage

No seeds data link

How many households use improved seeds there?

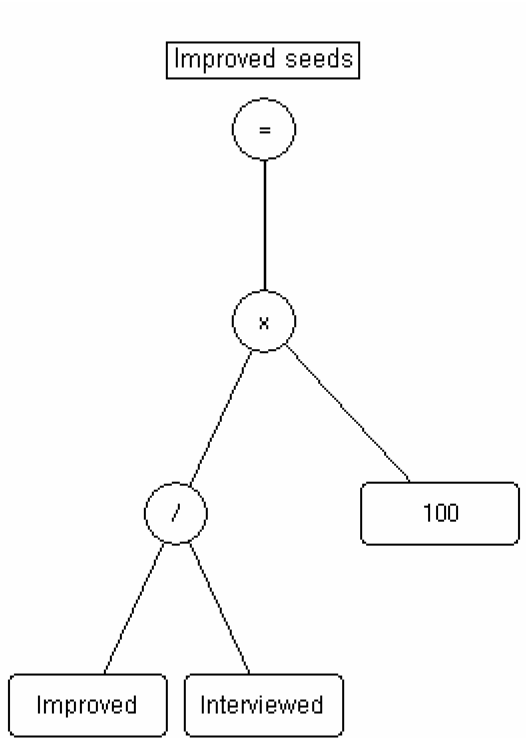
Fuzzy argument values: 0 = low (true); 100 = high (false) [5]

(Calculated data link) The corresponding calculation for this index is:

$$Seeds = \frac{\sum \ households \text{ using } \ improved\ seeds}{\sum \ Interviewed\ households} \times 100$$

Fig. 31 displays the improved seeds calculation. On the left side, Improved is divided by Interviewed and multiplied by 100 to obtain a percentage.

Figure 30. Calculation for use of improved seeds



Where,

- Improved represents the total number of households using improved seeds
- Interviewed is the total number of interviewed households
- 100 is a constant value, to obtain a percentage

No fallow data link

How many households not practicing fallow there?

Fuzzy argument values: 0 = low (false); 100 = high (true)[46]

(Calculated data link)

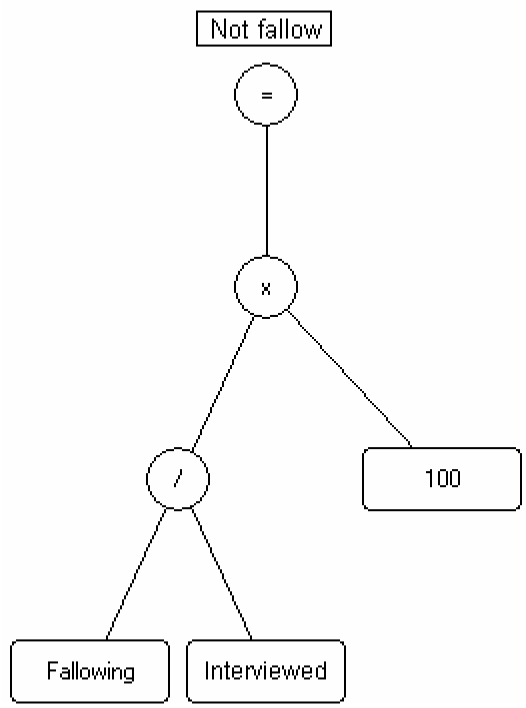
[46] For the model, these links are assumed to be positively affect the value for agricultural pressure

The corresponding calculation for this index is:

$$No\ fallow = \frac{\sum\ households\ not\ practicing\ fallow}{\sum\ \ Interviewed\ households} \times 100$$

Fig. 32 displays the no fallow lands calculation. At the left side, Fallowing is divided by Interviewed and multiplied by 100 to obtain a percentage.

Figure 31. Calculation for no fallow lands



Where,

- Fallowing represents the total number of households that do not leave lands fallow
- Interviewed is the total number of interviewed households
- 100 is a constant value, to obtain a percentage

Pasture data link

What is the mean area of cultivated pasture per household?

Fuzzy argument values: 1= low (false); 10= high (true)

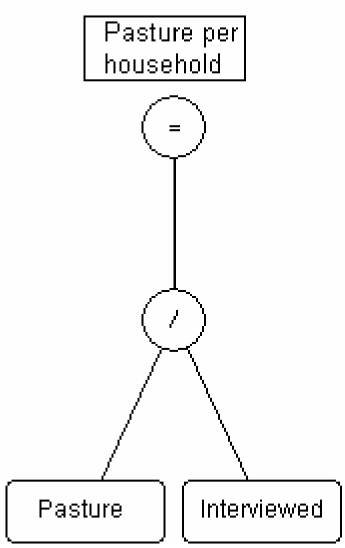
(Calculated data link).

The corresponding calculation for this index is:

$$Pasture\ area\ per\ household = \frac{Hectare\ pasture}{\sum \text{interviewed}\ households}$$

Fig. 33 displays the pasture area calculation. On the left side Ha pasture is divided by Interviewed obtaining the mean pasture area per household.

Figure 32. Calculation for pasture area per household



Where,

- Pasture represents the total area of cultivated pastures per village
- Interviewed is the total number of interviewed households

Housing & crop data link

What is the mean area destined for housing and cultivated crops per household?

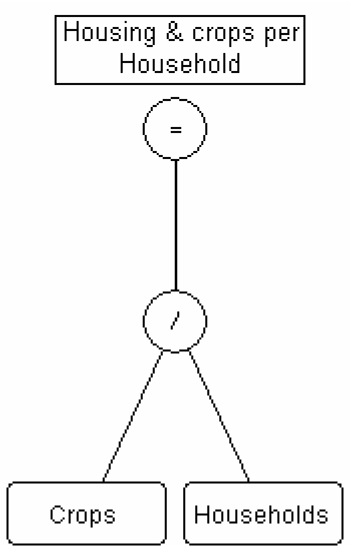
Fuzzy argument values: 1= low (false); 9= high (true)

(Calculated data link). The corresponding calculation for this index is:

$$\text{Housing}\ \&\ crop\ area\ per\ household = \frac{Hectare\ \text{housing \& crop area}}{\sum inhabited\ households}$$

Fig. 34 displays the housing and crops area calculation. On the left side, Ha crops is divided by Households, obtaining the mean housing and crops per household.

Figure 33. Calculation for housing & crop area per household



Where,

- Crops represents the total area per village used for housing and crops
- Households is the total number of inhabited houses per village

Crop production data link

What is the percentage of commercialized crop production per household?

Fuzzy argument values: 1= low (false); 100= high (true)

(Simple data link)

Cattle production data link

What is there the percentage of commercialized cattle production per household?

Fuzzy argument values: 1= low (false); 100= high (true)

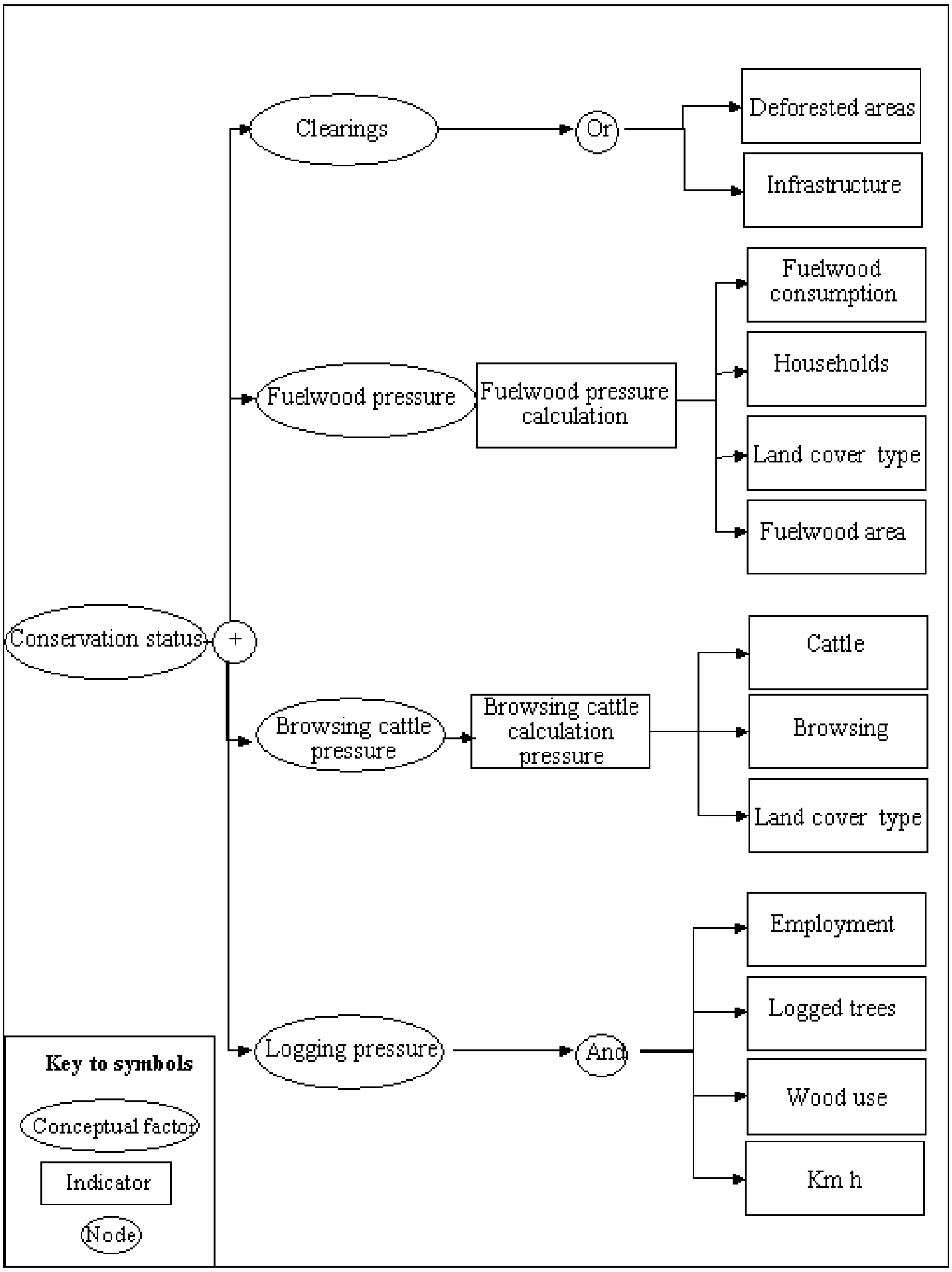
(Simple data link)

3.2.2.2 Meso-level knowledge-based model

The conceptual factors influencing the ecosystem outside of villages present a heterogeneous distribution in space and do not affect the overall research area in the same way; the indicators or sub-indicators are structured and interrelated in the meso-level model according to their areas or scopes of influence (see Fig. 34). The evaluation criterion for this knowledge-based model is: **Change in conservation status of ecosystems as result of land use, is maintained within acceptable limits**[47].

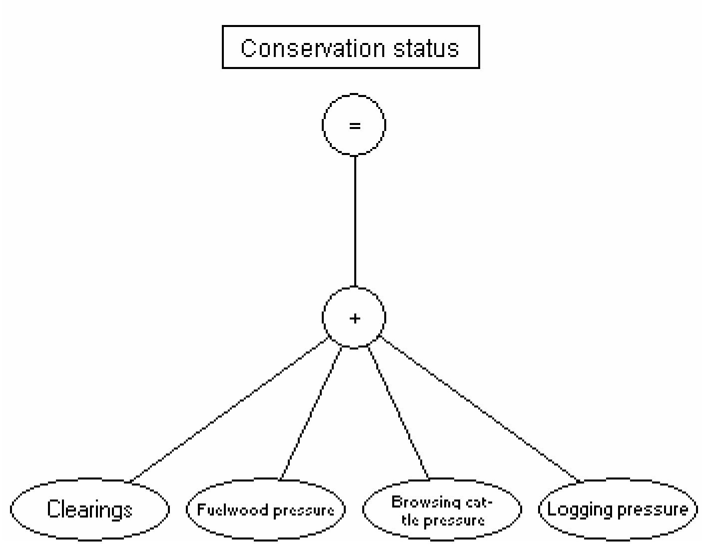
This knowledge-based model (Fig. 34) is comprised of one main dependency network, which is organized in four topics: clearing, fuel wood pressure, browsing cattle pressure, and logging pressure, whose partial evaluation results are added (Fig. 35).

Figure 34. Overview of meso-level model structure



[47] At least 50% of the monitoring area presents a very good conservation status.

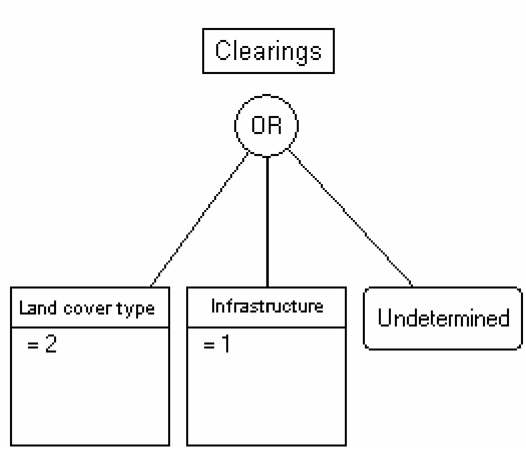
Figure 35. Conservation status dependency network



3.2.2.2.1 Clearings topic

This topic directly evaluates the worst ecosystem state, namely the deforested areas, using crisp arguments (see section 2.5.2). To complement the information about the deforested areas obtained from the land cover map ("land cover type" in Fig. 37) the known infrastructure is joined by means of an "Or" node. Areas not identified as "deforested" remain outside the evaluation performed by this topic and take an undetermined value.

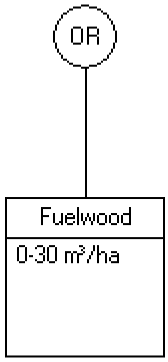
Figure 36. Deforested areas topic



3.2.2.2.2 Fuel wood pressure topic

This topic evaluates the fuel wood consumption pressure index, using one calculated data link (see Fig. 38). The data are obtained from household interviews (see section 3.2.4.2.2).

Figure 37. Fuel wood pressure data link



Fuel wood pressure data link

The respective question and evaluation argument for this data link follows:

To what degree is there a fuel wood consumption pressure?

Fuzzy argument values for evaluation: 0=Neither; 37=High[48]. Measure Unit= m^3/ha of fuel wood.

To obtain this index following calculation is required:

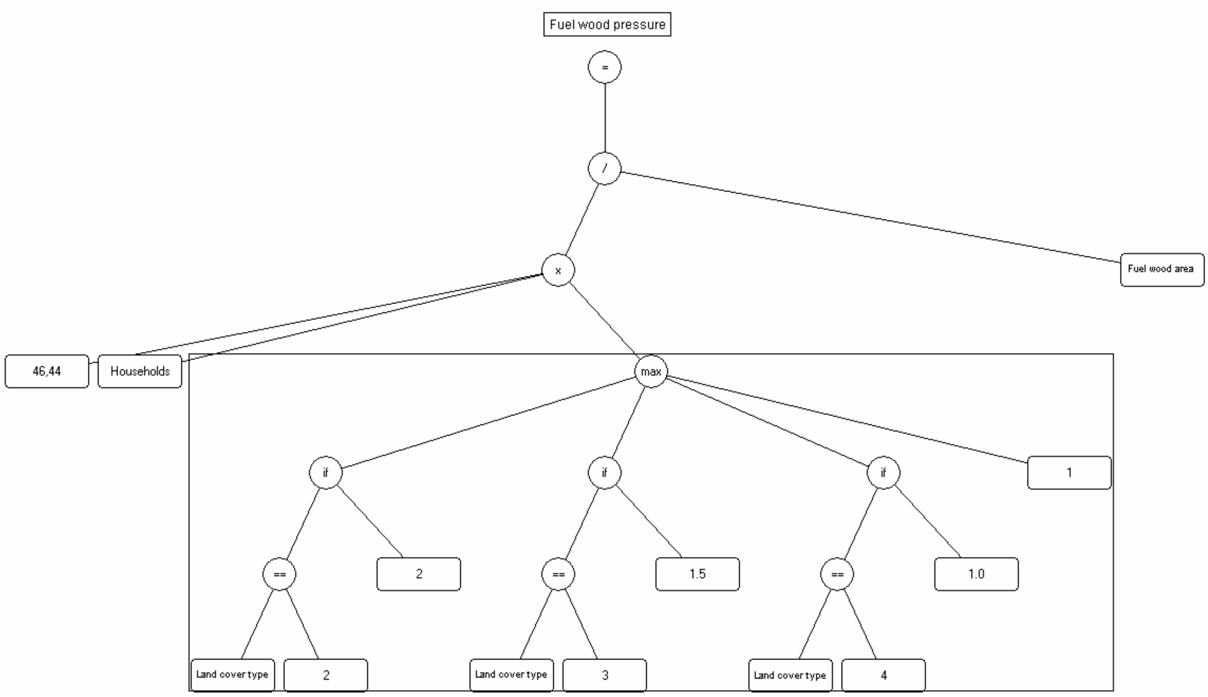
$$Fuelwood\ pressure = \frac{Population \times Fuelwood\ consumption \times Land\ cover\ type}{Fuelwood\ collection\ area}$$

Fig. 39 displays the fuel wood pressure calculation. On the left side, the annual fuel wood consumption <u>46.44</u> is multiplied by <u>Households</u> and the maximum value of <u>Land cover type</u> (delimited within the rectangle). <u>Land cover type</u> is represented by tree options which follow from the left to the right as: if <u>Land cover type</u> is equal to 2 then the value of 2 is incorporated to the calculation, if it is equal to 3 then the value of 1.5, and it is equal to 4 then the value of

[48] This value corresponds to the minimum volume of wood determined by [Superintendencia Forestal 1999] for the Chiquitania region.

1; the most right value 1 do not affect the calculation (see details on the next page). Fuel wood area divides this outcome.

Figure 38. Fuel wood pressure calculated data link



Where,

- 46.44 (m^3) is a constant value, representing the annual mean of fuel wood consumed per household
- Households is the total number of inhabited houses per village
- Fuel wood area is the collection area
- 1 If no land cover data is given, the default value of 1 will be used
- Land cover type can take one of these tree values: 2= deforested areas,
  3= open canopy areas and
  4= closed canopy areas.

  Each land cover type offers a different degree of resistance influencing the transport cost across and thus the fuel wood collection. They are ranked and weighted according to this respective influence degree as shown in Table 9. For example, a middle weight (1.5) is incorporated into the calculation if the terrain has a land cover type identified with the value 3.

Table 25. Weight's scale for land cover related to fuel wood pressure

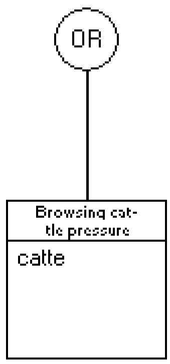
Land cover type	Value	Explanation
Deforested areas (e.g. burnt plots for agriculture)	2	Lowest resistance and transport cost, easiest fuel wood collection
Open canopy areas	1.5	Middle resistance and transport cost, moderate effort for fuel wood collection
Closed canopy areas	1	Highest resistance and transport cost, high effort for fuel wood collection

Actual data for a given year are stored in the vector data layer that corresponds to the fuel wood collection area (see indicator 11).

3.2.2.2.3 Browsing cattle pressure topic

This topic evaluates cattle browsing pressure index, using a calculated data link (Fig. 40). Data are obtained from household interviews (see section 3.2.4.2.2).

Figure 39. Browsing cattle pressure topic



Browsing cattle data link

The respective questions and evaluation arguments the data link follows:

To what degree is there a pressure due to the browsing of cattle?

Fuzzy argument values for evaluation: 1= low (1 LU/40 ha or 0.025 LU/ha); 3= high (3 LU/40 ha or 0.075 LU/ha)[49]. The actual cattle density (LU/ha) is compared to the low density as follows:

$$Cattle\ \ pressure\ =\ \frac{Cattle\ Density}{Normalized\ density\ (low\ density)}$$

$$= \frac{Cattle\ (actual\ data) / \text{Browsing}\ \ area\ (actual\ data)}{1LU/40\ ha}$$

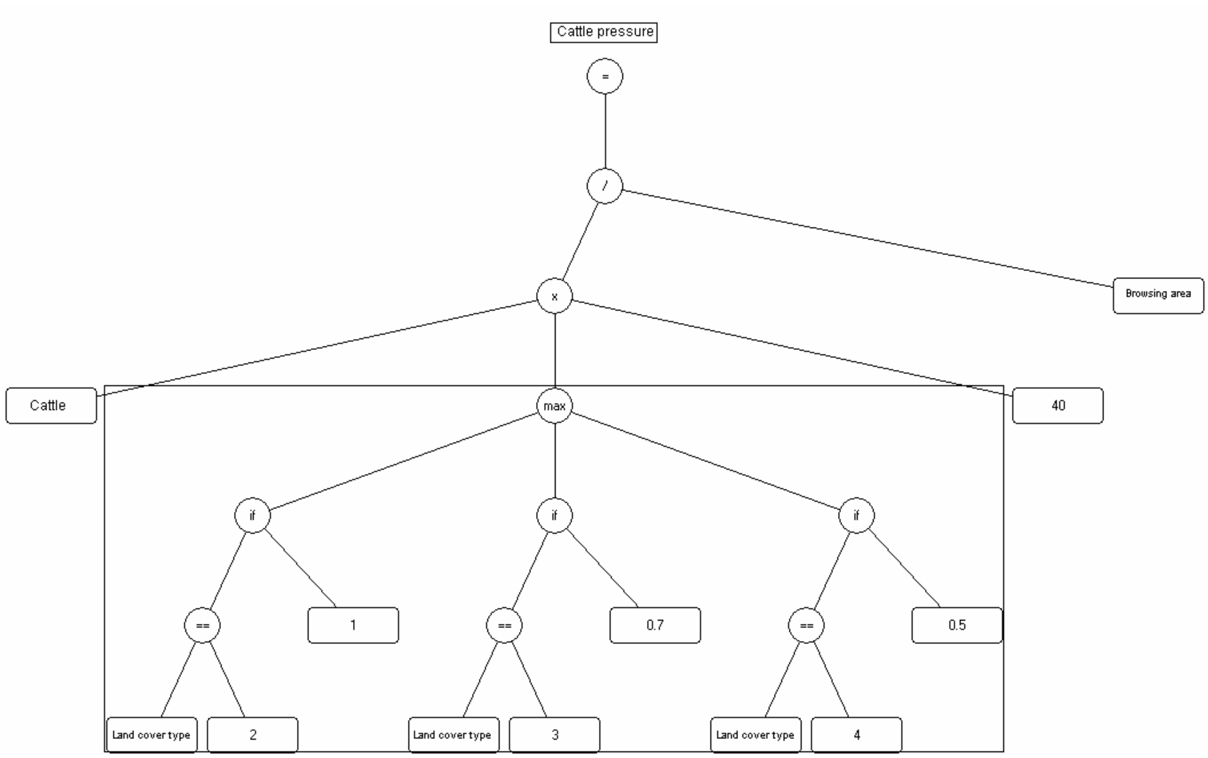
To obtain the cattle browsing pressure index the following calculation is required, as illustrated in Fig. 41:

$$Cattle\ \ pressure = \frac{Cattle \times 40\ ha \times Land\ \ \text{cov}er\ type}{Browsing\ \ area}$$

Fig. 41 displays the cattle pressure calculation. On the left side, the total number of Cattle per village is multiplied by 40 (see explanation below) and the maximum value of Land cover type (delimited within the rectangle). Land cover type is represented by tree options, which follow from the left to the right as: if Land cover type is equal to 2 then the value of 1 is incorporated to the calculation, if it is equal to 3 then the value of 0.7 is incorporated, and if it is equal to 4 then the value of 0.5 is incorporated. This outcome is divided by browsing area.

[49] Compared to the carrying capacity of natural vegetation in the Chiquitania region for browse of cattle, equivalent to *14.0 ha per livestock unit (LU)* [Columba 2002], which can also be represented as: 1LU/14 ha or 0.071.

Figure 40. Pressure of browsing cattle, calculated data link



Where,

- Cattle is the total number of cattle per village
- 40 (ha) is a constant value, representing the browsing area of the normalized density (1LU/40 ha)
- Browsing area is the area of browsing
- Land cover type can take one of these tree values: 2= deforested areas,
  3= open canopy areas and
  4= closed canopy areas.

  Each land cover type offers a different degree of resistance, which influences the cost of transport as well as the extent of grazing and trampling actions. They are ranked and weighted according to its respective influence degree (Table 26), e.g. a middle weight (0.7) is incorporated to the calculation if the terrain has a land cover type identified with the value 3.

Table 26. Weight's scale for land cover type related to cattle pressure

Land cover type	Value	Explanation
Deforested areas	1	Lowest resistance and transport cost, easiest cattle access
Open canopy areas	0.7	Middle resistance and transport cost, moderate cattle access
Closed canopy areas	0.5	Highest resistance and transport cost, high effort for cattle to access

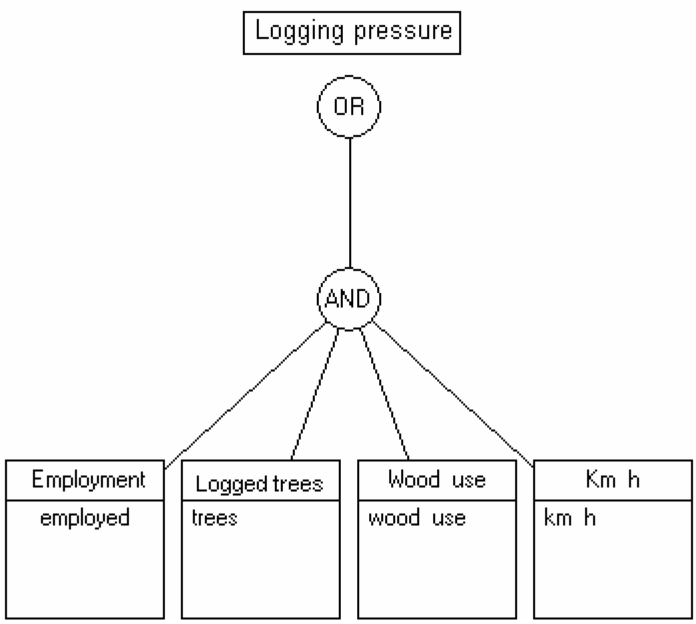
Actual data for a given year are stored in the vector data layer that corresponds to the cattle potential area of browsing (see indicator 17).

3.2.2.2.4 Logging pressure topic

This topic evaluates the logging pressure using four data links (Fig. 42). Data are obtained from household interviews excluding the information about Km per hour on all year roads; this ratio is obtained from the survey (see section 3.2.4.2.2).

Fig. 42 displays the logging pressure topic. Its corresponding data links are averaged by means of an "And" node.

Figure 41. Logging pressure topic



Employment data link

This calculated data link evaluates the question:

To what degree is the manpower potentially employed in logging?

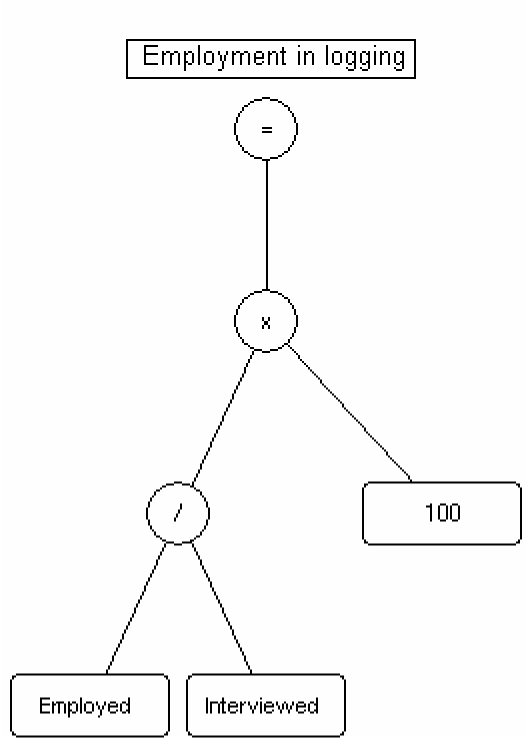
Fuzzy argument values for evaluation: 1 = low; 100 = high. Measure unit= percentage

The corresponding calculation for this index (as shown in Fig. 7) is:

$$\textit{Manpower with potential employment in } \text{logging} = \frac{\sum \textit{ households without fixed employment}}{\sum \textit{ Interviewed households}} \times 100$$

Fig. 43 displays the employment in logging calculation. On the left side, Employed, or total households with potential employment in economic activities causing deforestation, is divided by Interviewed and multiplied by 100 to obtain a percentage.

Figure 42. Calculation of manpower with potential employment in logging



Where,

- Employed represents the total households with potential employment in economic activities causing deforestation

- Interviewed is the total number of interviewed households
- 100 is a constant value, to obtain a percentage

Logged trees data link

The calculated data link logged trees evaluates the question:

How many trees were logged there in a given year?

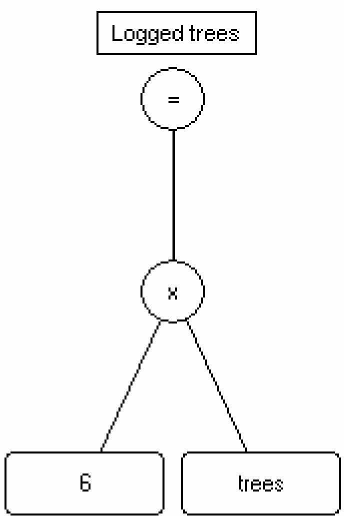
Fuzzy argument values for evaluation: 0= none; 3.400.000[50] = high. Measure unit= tree/year

The corresponding calculation for this index is:

$$\textit{Logged trees} = \textit{Number of monthly} \text{ logged } \textit{trees} \times 6$$

Fig. 44 displays the calculation-logged trees in a determined year. On the left side, 6 is multiplied by Trees.

Figure 43. Calculation of number of logged trees



Where,

- 6 represents a constant value, since the logging operations take place only 6 months per year
- Trees is the total number of logged trees per month

[50] This value depends on the area of logging and therefore should be updated for subsequent M&E periods. To obtain this value, the potential area of logging (see Indicator 13) is multiplied by the constant value 23.5 (tree/ha). This constant value represents the number of trees potentially utilizable per hectare according to inventories performed in the region by [Superintendencia Forestal 1999].

Wood use data link

The simple data link wood use evaluates the question:

What is the most important use of wood?

Fuzzy argument values for evaluation: 1 (individual) = low; 2 (sell) =high.

Km per hour data link

The simple data link Km h evaluates the question:

What is there the average speed of travel?

Fuzzy argument values for evaluation: 1 km /hour =low; 100 km /hour =high

Actual data for a given year are stored in the vector data layer that corresponds to the area of logging (see indicator 13).

3.2.3 Validation of the system and baseline M&E

This section depicts the field data used for validation of the models as well as the spatial evaluation of both (field data and models), which was done in a cyclic process (see section 2.6). The spatial evaluation was reached by means of the models' performance; the corresponding results are graphically exposed according to their area of influence.

3.2.3.1 Village-level evaluation results

3.2.3.1.1 Agricultural pressure evaluation

At the village level, there is a moderate (San Juan de Chiquitos) to strong (Entre Ríos, Ramada and Buena Vista) pressure on the surrounding forest, due to the agricultural practices of fully extensive farming (see Fig. 45).

The *technological level* is quite low: no agrochemicals are used, no irrigation is being carried out, and the types of tools utilized for farming are hoe and spade. Improved seeds are the unique sub-indicator to take into consideration assessing the technological level. The proportion of households using improved seeds in the small villages is considerably higher than in larger villages (Table 27). The PDI had a larger impact in small villages. All these data lead to an increase in the calculated value for agricultural pressure.

Table 27. Indicator 1 Technological level

Sub-indicator description		Entre Ríos	Ramada	San Juan de Chiquitos	Buena Vista
Percentage of households that	Number	8	10	10	26
use improved seeds	Per cent	72.70	76.90	33.30	36.10
Percentage of households that	Number	0	0	0	0
use chemical fertilizer	Per cent	0.00	0.00	0.00	0.00
Area under irrigation	Number	0	0	0	0
Type of tools utilized	Number	1[51]	1	1	1

In relation to the *proportion of households not practicing fallow*, there are remarkable differences between villages. Ramada is the unique village where fallow is still practiced by more than 50% of households (Table 28). In the other villages fallow is practiced to a smaller degree, alternating between 36.4% (Entre Ríos) and almost 20% (San Juan de Chiquitos).

Table 28. Indicator 2 Percentage of households not practicing fallow

Village	Number	Per cent
Entre Ríos	7	63.60
Ramada	6	46.20
San Juan de Chiquitos	24	80.00
Buena Vista	51	70.80

Concerning *the mean land area per household* there are distinctions between villages (Fig. 44 and Table 29). The largest area is used in Entre Ríos (14.97 ha/Hh), followed by Ramada (12.3 ha/Hh) and Buena Vista (12.1 ha/Hh). Households in San Juan de Chiquitos use considerably less area in relation to the rest of the villages (3.21 ha/Hh). The data for the first three villages supposedly foment agricultural pressure, whereas the data of the last one restrict it.

San Juan de Chiquitos appears to be an exception (see households density in Table 29): in contrast to the other villages, where the households are dispersed, in San Juan de Chiquitos

[51] See: No mechanization data link

houses are distributed closer to each other. Jesuits funded the town three centuries ago, and even today it keeps the same colonial structure of urbanization. Furthermore and in relation to farming, this village presents the highest rate of manpower with continuous employment in non-deforestation activities (18%) (see Appendix XI). Both aspects influence the total land area used.

Figure 44. Indicator 3 Mean land area used per household

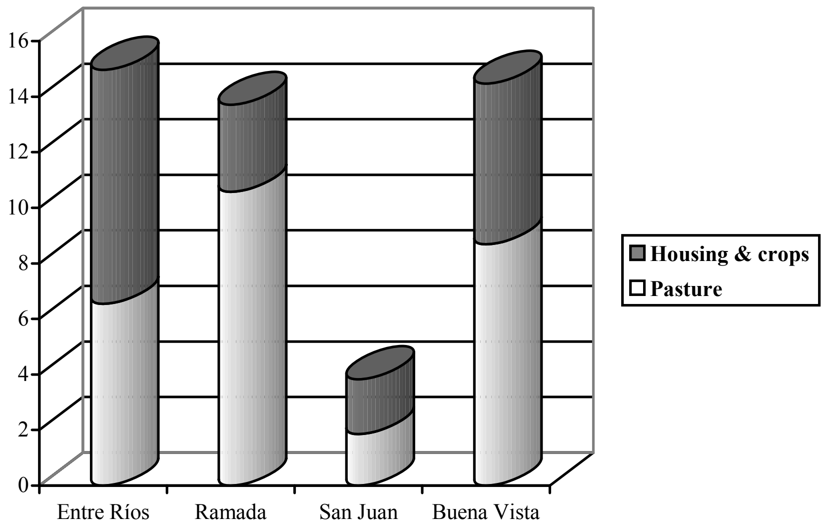


Table 29. Indicator 3 Mean land area used per household and distribution of villages' land use

Description	Entre Ríos	Ramada	San Juan de Chiquitos	Buena Vista
Sub-indicator: Cultivated area of pastures per interviewed household	6.55	10.58	1.86	8.69
Sub-indicator: Housing and crop areas per inhabited household	8.42	3.13	1.97	5.78
Total pastures (ha)	72.00	137.60	56.00	626.00
Total housing and crops areas (ha)	92.60	47.03	88.5	571.92
Total village area	164.6	184.63	144.5	1 197.92
Households density (Hh/ha)	0.06	0.08	0.31	0.08

Farming is partly commercialized, since the *proportion of commercialized crop products* is below 50% in all villages. The level of crop commercialization is low (Table 30), oscillating from 24.59% to 3.90% (Ramada and Buena Vista, respectively). These data lead to an decrease in the calculated value for agricultural pressure.

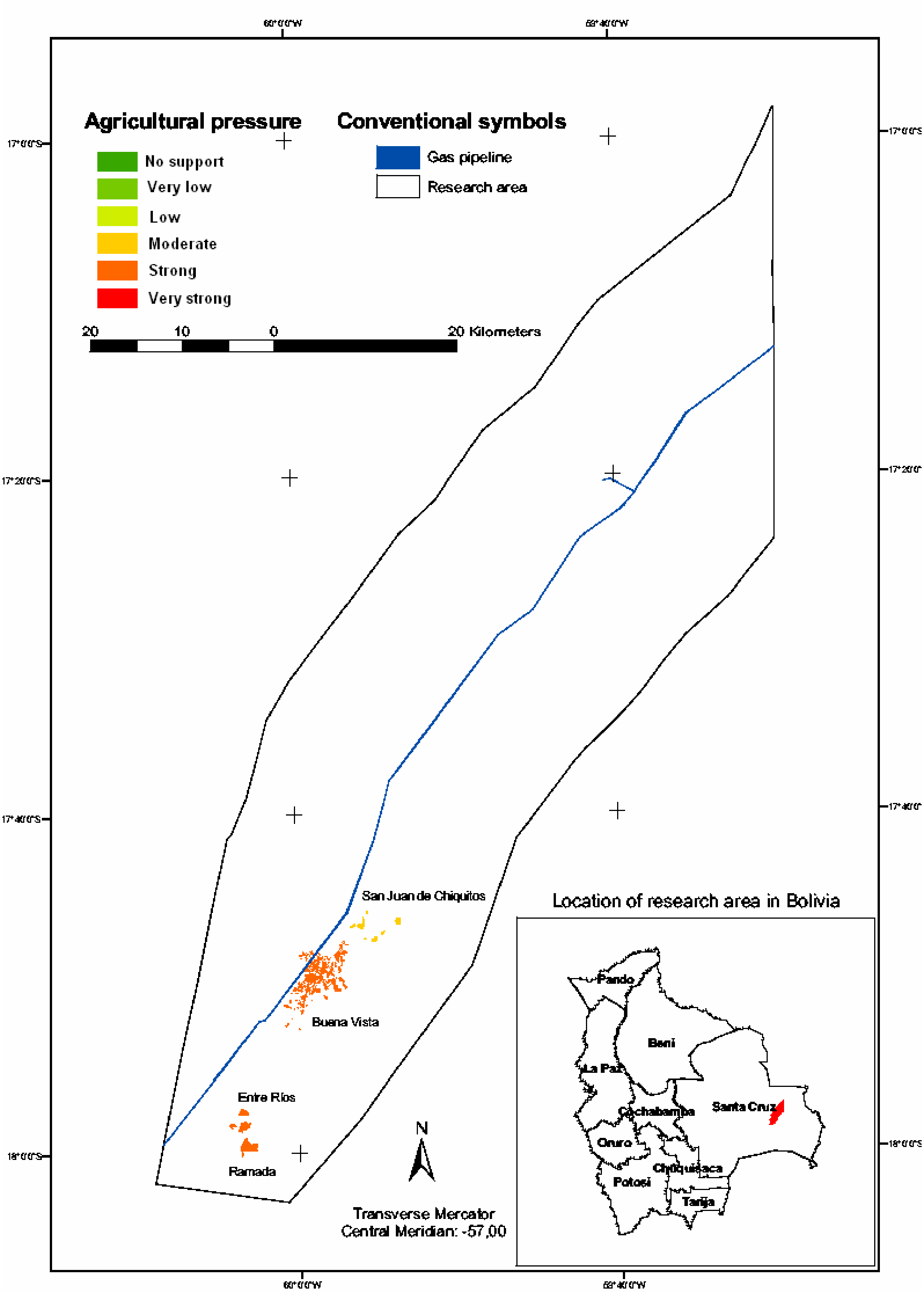
Table 30. Indicator 4 Proportion of commercialized farm produce

Sub-indicator description	Village	Σ percentage Commercialized Harvest	Number of Households with crops	Percentage of Commercialized Production /village
Percentage of commercialized crop production[52] per household	Entre Ríos	53.61	8	6.70
	Ramada	270.56	11	24.59
	San Juan de Chiquitos	113.03	16	7.06
	Buena Vista	183.75	47	3.90
Percentage of commercialized cattle production per household	No data were collected related to this aspect; therefore it was left out of the evaluation in this year.			

Concerning credits by the gas company: As expected, in this year there is no *provision of financial incentives for the expansion of the agricultural lands* (see Indicator 6).

[52] Production measured in kilograms.

Figure 45. Level of agricultural pressure in the research villages[53]



[53] See key to categories in Appendix XIII.

3.2.3.2 Meso-level evaluation results

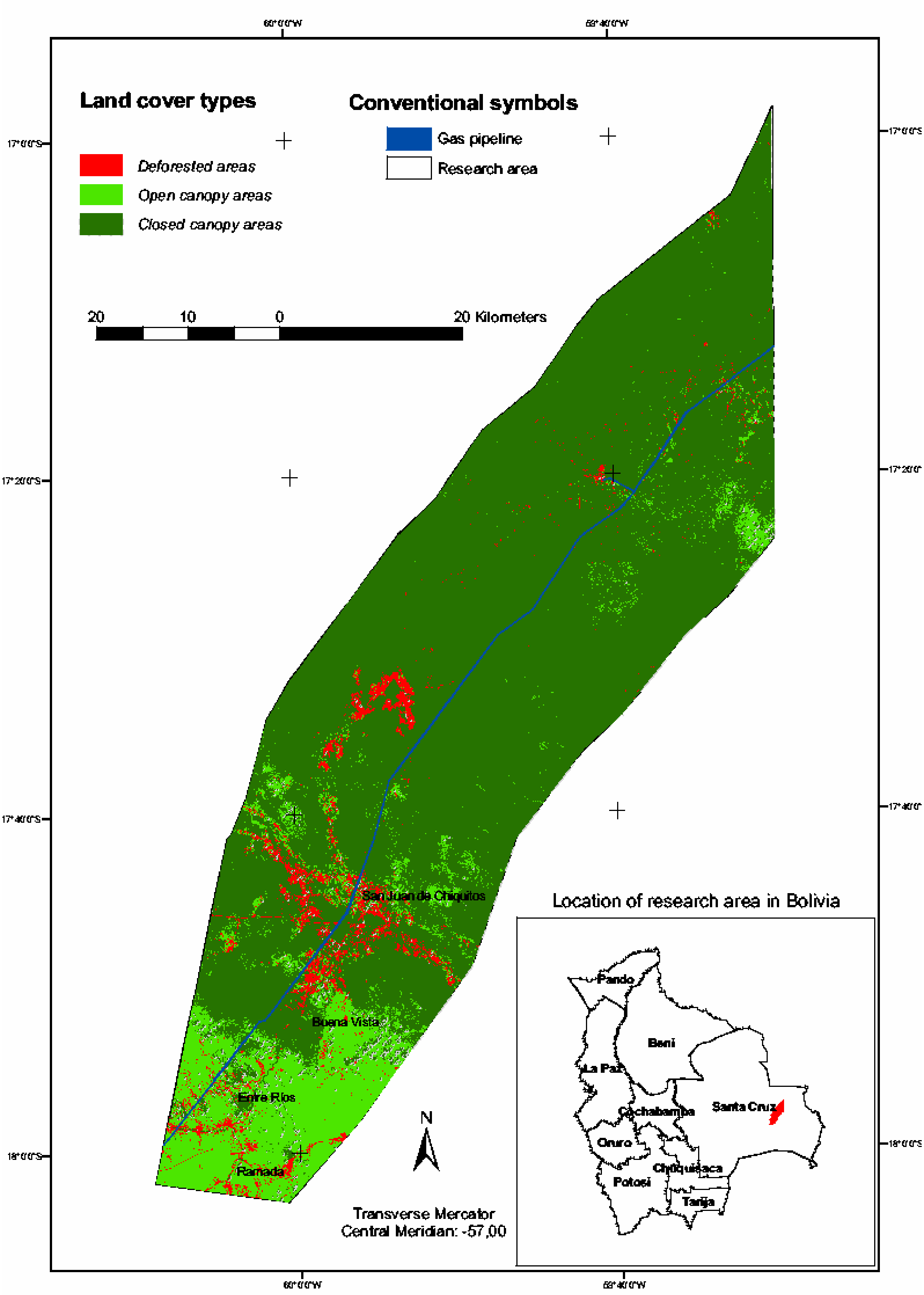
3.2.3.2.1 Deforested areas evaluation

In the research area natural vegetation prevails (Fig. 47). Natural vegetation makes up a percentage of 96.42; of this area, 13.70% corresponds to open canopy areas and 82.72% to closed canopy areas. Deforested areas correspond to 3.58%. These areas lie outside the boundaries of human settlements; according to field observations, these areas are linked to logging activities.

Table 31 Land cover areas in year 2002

Description	Per cent
Indicator 7 Deforested areas	3.58
Indicator 8 Natural vegetation areas	96.42
Sub-indicator: Open canopy areas	13.70
Sub-indicator: Closed canopy areas	82.72

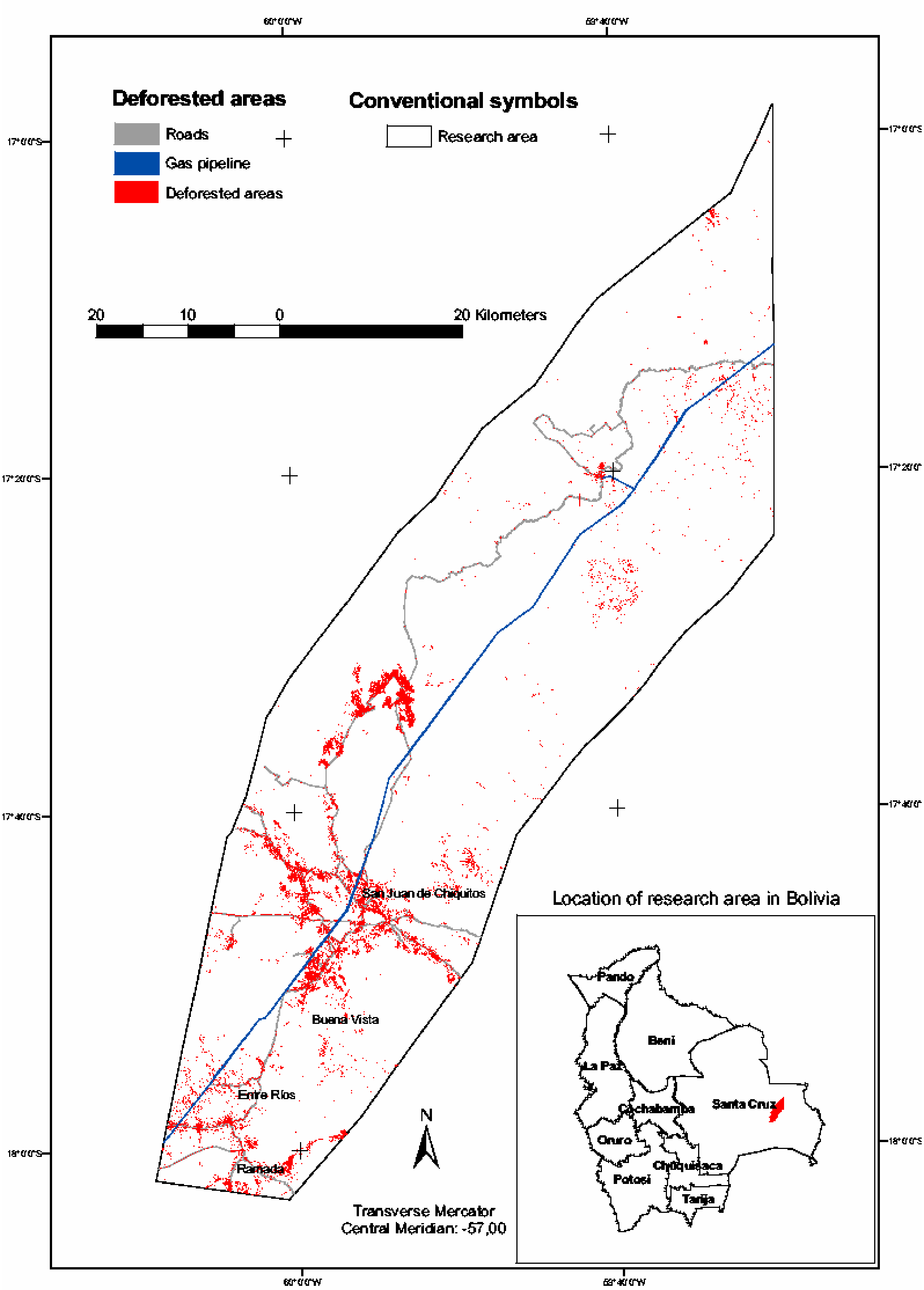
Figure 46. Land cover map year 2002



As expected from the model, the areas identified as “deforested” in the land cover layer and those corresponding to infrastructure[54] are evaluated directly as the worst state of the ecosystem (Figs. 47 and 48). The rest of the land cover types remain outside this evaluation.

[54] 340.40 ha corresponding to gas pipeline and road network.

Figure 47. Deforested areas map year 2002



Source: Deforested areas from interpretation of Landsat ETM+ image by author. Gas pipeline and roads from [Céspedes *et al.* 2002] complemented by author.

3.2.3.2.2 Fuel wood pressure evaluation

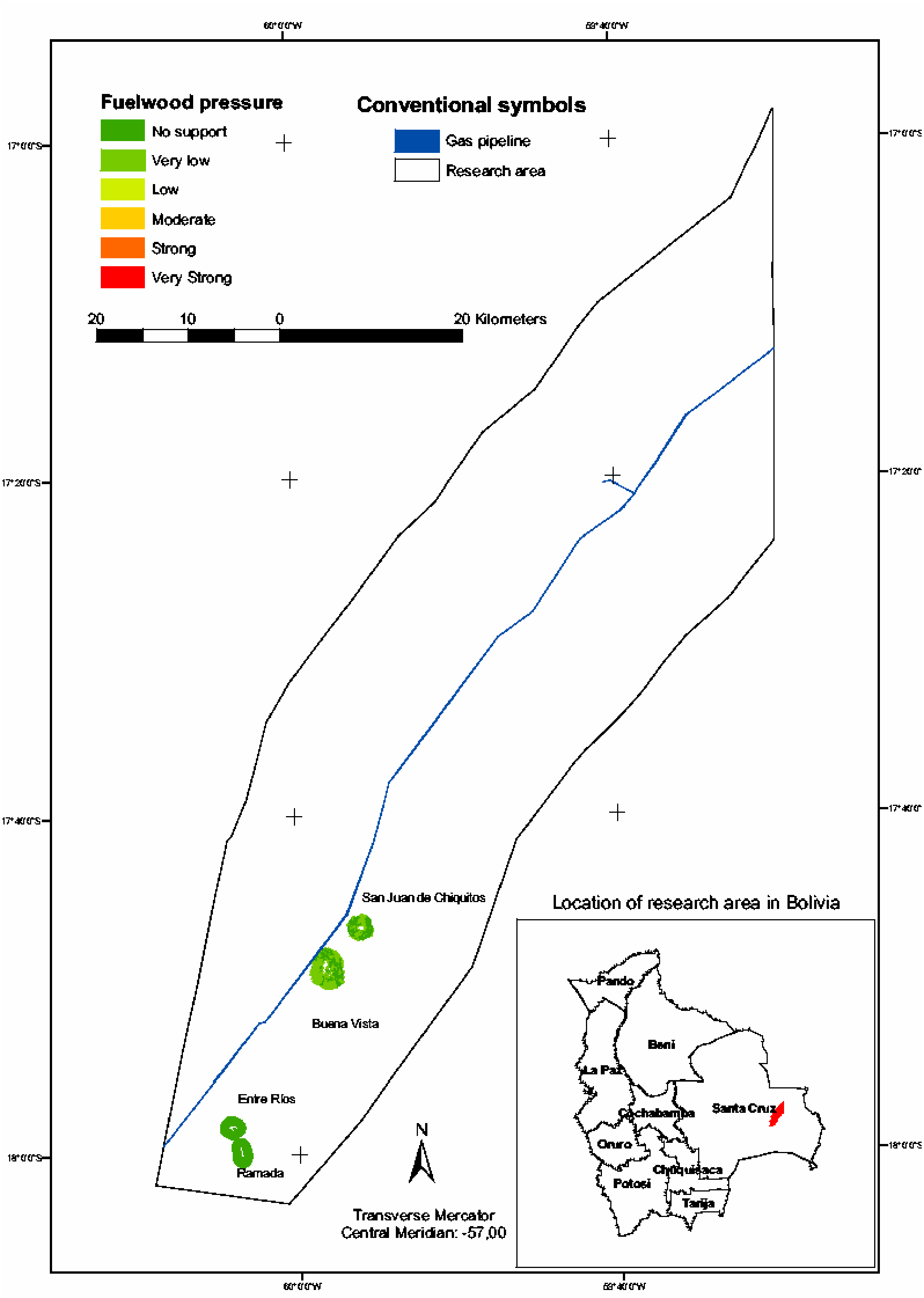
The population of the research villages is significantly small (Table 32), varying from 11 (Entre Ríos) to 99 (Buena Vista) inhabited households. Depending on population size and assuming a regular consumption of 46.44 m^3/year of fuel wood, the fuel wood needs per household oscillate between 510.84 and 4 597.56 m^3 respectively. Accordingly, the potential area of fuel wood collection has the smallest extension in Entre Ríos (562.06 ha) and the largest in Buena Vista (1 093.01).

Table 32. Data relating to fuel wood pressure in year 2003

Indicator description	Village	Total number of households	Annual estimated fuel wood consumption (m^3)
9 Number of inhabited houses	Entre Ríos	11	510.84
	Ramada	15	696.60
	San Juan de Chiquitos	45	2 089.80
	Buena Vista	99	4 597.56
10 Potential area of fuel wood collection (see Fig. 48)	**Village**	**Hectares per village**	**Households/ha**
	Entre Ríos	562.06	0.01
	Ramada	576.84	0.02
	San Juan de Chiquitos	598.55	0.07
	Buena Vista	1 093.01	0.09

The areas influenced by fuel wood collection are depicted in Fig. 48, which indicates that in 72.50% of the total research area, the fuel wood collection pressure is almost non-existent, whereas 27.50% has a very low-pressure level. As expected from the model, the areas showing a higher level of pressure also correspond to those villages with a higher household density and to the land cover type most suitable for fuel wood collection (see section 3.2.2.2.2.).

Figure 48. Areas influenced by fuel wood collection and its level of use pressure[55]



[55] See key to categories in Appendix XIII.

3.2.3.2.3 Cattle pressure evaluation

The amount of cattle in the research area is low: the total holding in the villages consists on about 1500 animals. The mean number of cattle per household, under free browse management, differs in a minimal degree between villages; the minimum value is 11.53 LU/Hh in Ramada and the maximum 13.36 in Entre Ríos (Table 33). Depending on the different perimeters of the villages, the smallest potential area of browsing corresponds to Entre Ríos (5 782.23 ha) and the largest to Buena Vista (9 205.34 ha).

Table 33. Data concerning cattle pressure in year 2003

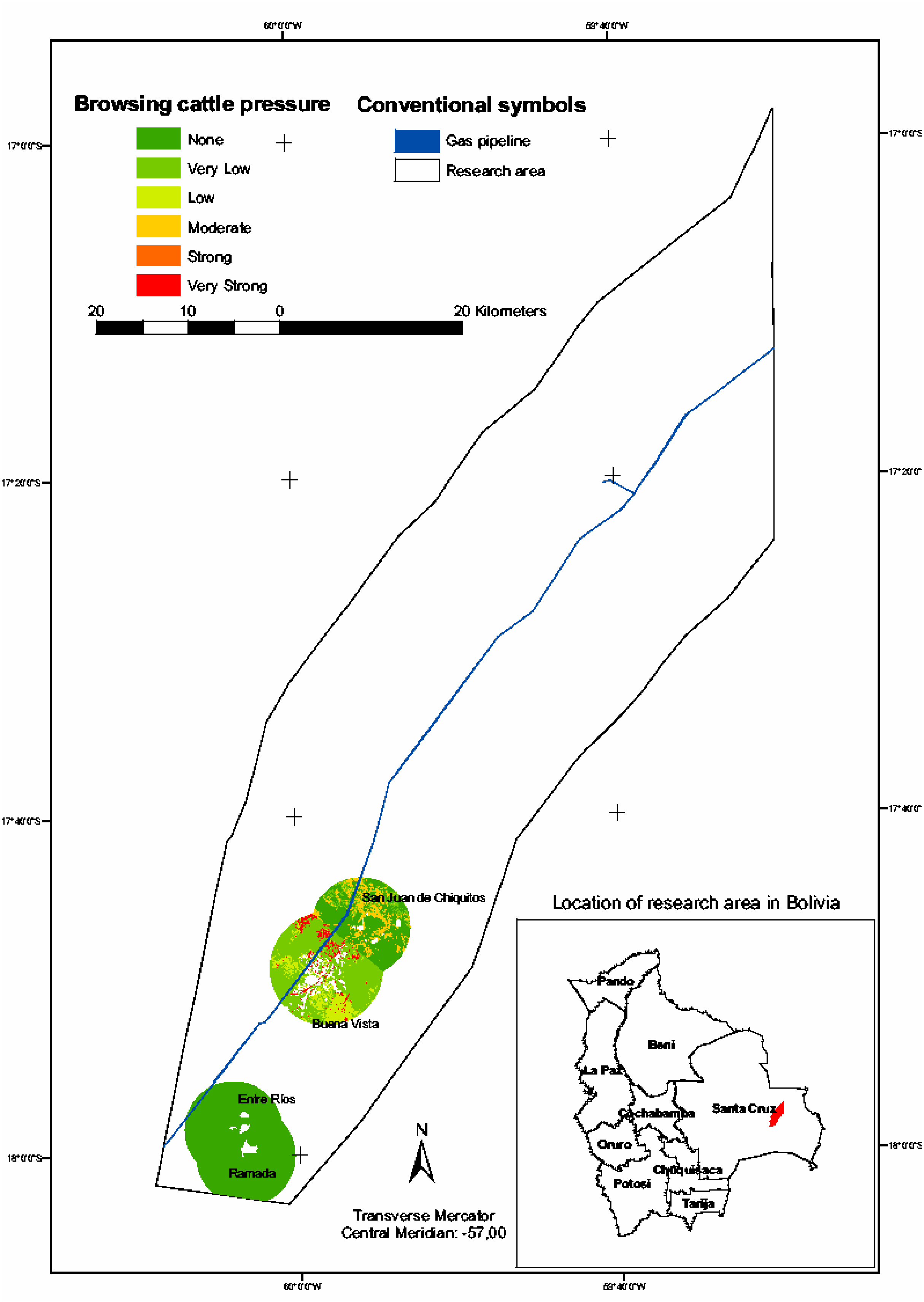
Indicator description	Village	Total cattle	Mean LU / Interviewed households	
16 Number of cattle	Entre Ríos	147	13.36	
	Ramada	150	11.53	
	San Juan de Chiquitos	351	11.70	
	Buena Vista	618[56]	11.91	
17 Potential area of browsing (see Fig. 50)	**Village**	**Hectares**	**Ha/Lu (or)**	**LU/Ha**
	Entre Ríos	5 782.23	39.33	0.02
	Ramada	6 440.69	42.93	0.02
	San Juan de Chiquitos	6 876.77	19.59	0.05
	Buena Vista	9 205.34	14.89	0.06

Fig. 49 indicates the areas influenced by free browsing of cattle and shows the different levels of cattle pressure. In a fashion similar to fuel wood pressure, the cattle pressure is almost non-existent or very low in the majority of the affected zone. A proportion of 54.98% of the area do not show any pressure; these areas correspond to the total browsing areas of Entre Ríos and Ramada and to the part of San Juan de Chiquitos that are closed forest areas. A very *low* level of pressure was observed in 30.76% of the area, corresponding mainly to Buena Vista

[56] Since 240 LU graze only on pasture lands, they remained outside this analysis.

and in a smaller extension to San Juan de Chiquitos. 6.37% of *low* cattle pressure and 2.81% of areas under *very strong* pressure belong to Buena Vista. The rest (5.09 %) consists of areas under *strong* pressure in San Juan de Chiquitos. As expected from the model, the areas showing a higher level of pressure correspond to those with a higher cattle density (Table 33), and this pressure level varies depending on the existent land cover type.

Figure 49 Areas influenced by cattle browsing and its level of pressure[57]



[57] See key to categories in Appendix XIII.

3.2.3.2.4 Logging pressure evaluation

Logging pressure in the research area is very low (Fig. 50). In 2003 logging density was 0.12 tree/ha. Compared to the total tree density of 23.5 tree/ha[58], the logging pressure appears to be very small. The potential area of logging is large and the number of logged trees low (17 940 trees in this year). Moreover, with a possible travel speed of 20 km/h on all-year roads, the quality of the road network in the research area is low. The levels of these three indicators are negatively affecting the value for logging pressure. In contrast, the estimated manpower with potential employment in logging in the villages is high (81.74%). In addition, the main use given for the timber was *trade*. Both factors currently exert a positively affect the value for logging pressure. As expected from the model, the average of those values is low (Table 34).

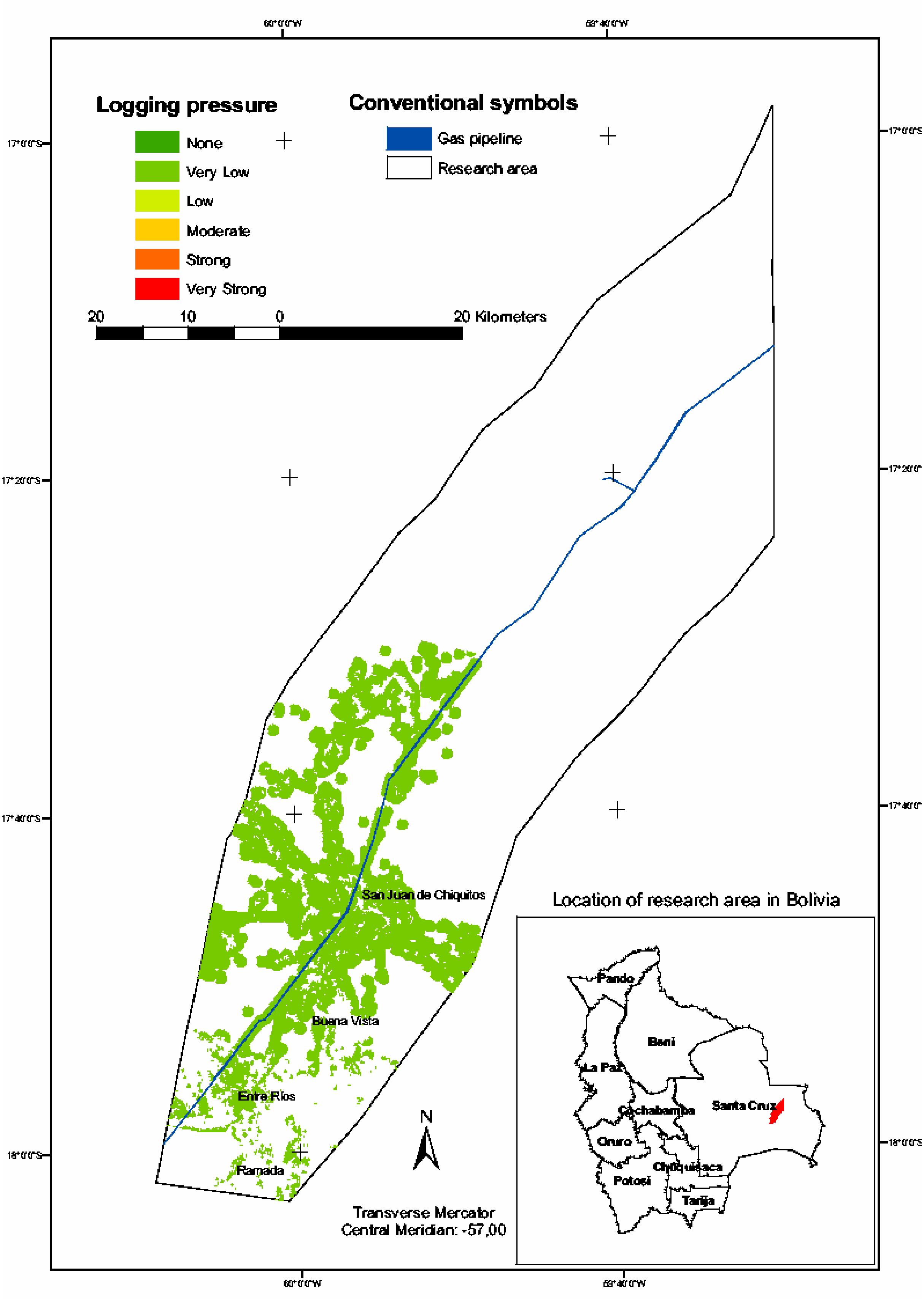
Logging pressure is very difficult to determine since timber extraction is to some degree an illegal activity. Therefore, it is likely that people give biased information (see indicator 14). However, accurate information about the logging area does not exist. The areas allowed by law for forest exploitation do not match up with the observed deforested areas (see Appendix XII) and most significant logging activities are being carried out in areas without legal concession for such exploitation. The actual exploited areas are not being managed properly; otherwise, the remote sensor could not detect deforestation. Despite the generality of indicator 13 its informational value is regarded as good.

Table 34. Indicators concerning to logging pressure in year 2003

Indicator description	Data	
5 Average travel speed on all year road	20 km /hour	
12 Estimated percentage of manpower with potential	Number	Per cent
employment in logging	103.00	81.74
13 Potential area of logging (see Fig. 50)	148 069.69 ha	
14 Number of trees logged monthly	2 990.00 trees	
15 Main use given for the timber	Trade	

[58] Potentially utilizable trees in the Chiquitano forest [Superintendencia Forestal 1999]

Figure 50 Areas influenced by logging and its level of pressure[59]



[59] See key to categories in Appendix XIII.

3.2.3.2.5 Conservation status evaluation

As depicted above in section 3.2.2.2, the general model for evaluation of the conservation status corresponds to the addition of the anthropogenic pressures influencing the vegetation cover.

Quite healthy ecosystems currently predominate in the research area. 82.96% of the total area under research has very good conservation status and 3.67% correspond to deforested areas. 12.66% of the area shows either good (11.33%) or moderate (1.84%) conservation status, and only 0.19% shows a poor level (see Figs. 51 and 52). The results agree with [Columba *et al.* 2002], who performed a similar assessment for the whole Chiquitania region.

As expected from the model, deforested areas show a status of *very critical* conservation. Areas assigned to the *natural areas* class and exposed to no anthropogenic pressure show *very good* conservation status. Areas designated as *natural areas* but exposed to a certain degree of human pressure present one of the following conservation statuses: *good, moderate, poor,* or *very poor*. Furthermore, the evaluation of areas exposed to two or three kinds of pressure (fuel wood extraction, logging, or browsing of cattle) corresponds to the aggregation of each independent pressure.

Figure 51. Hectares of conservation status categories

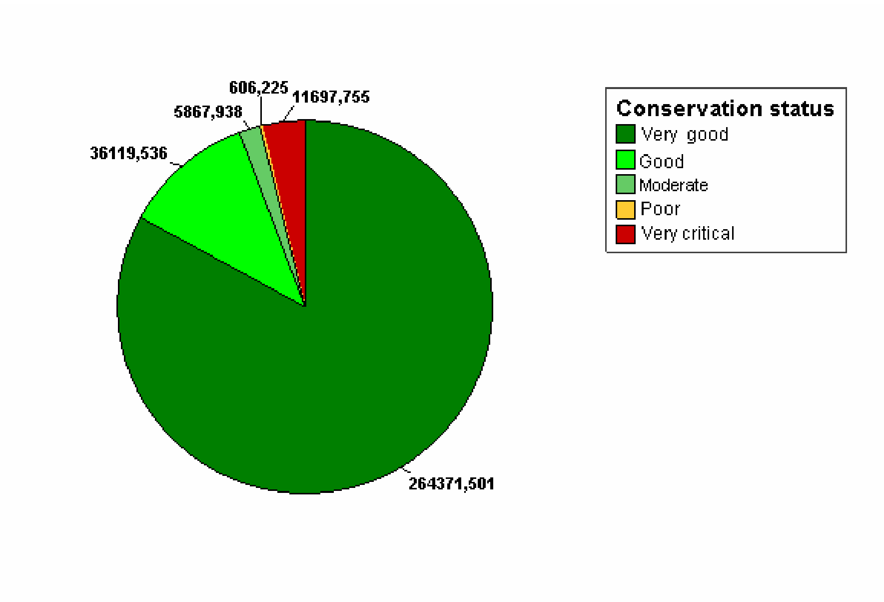
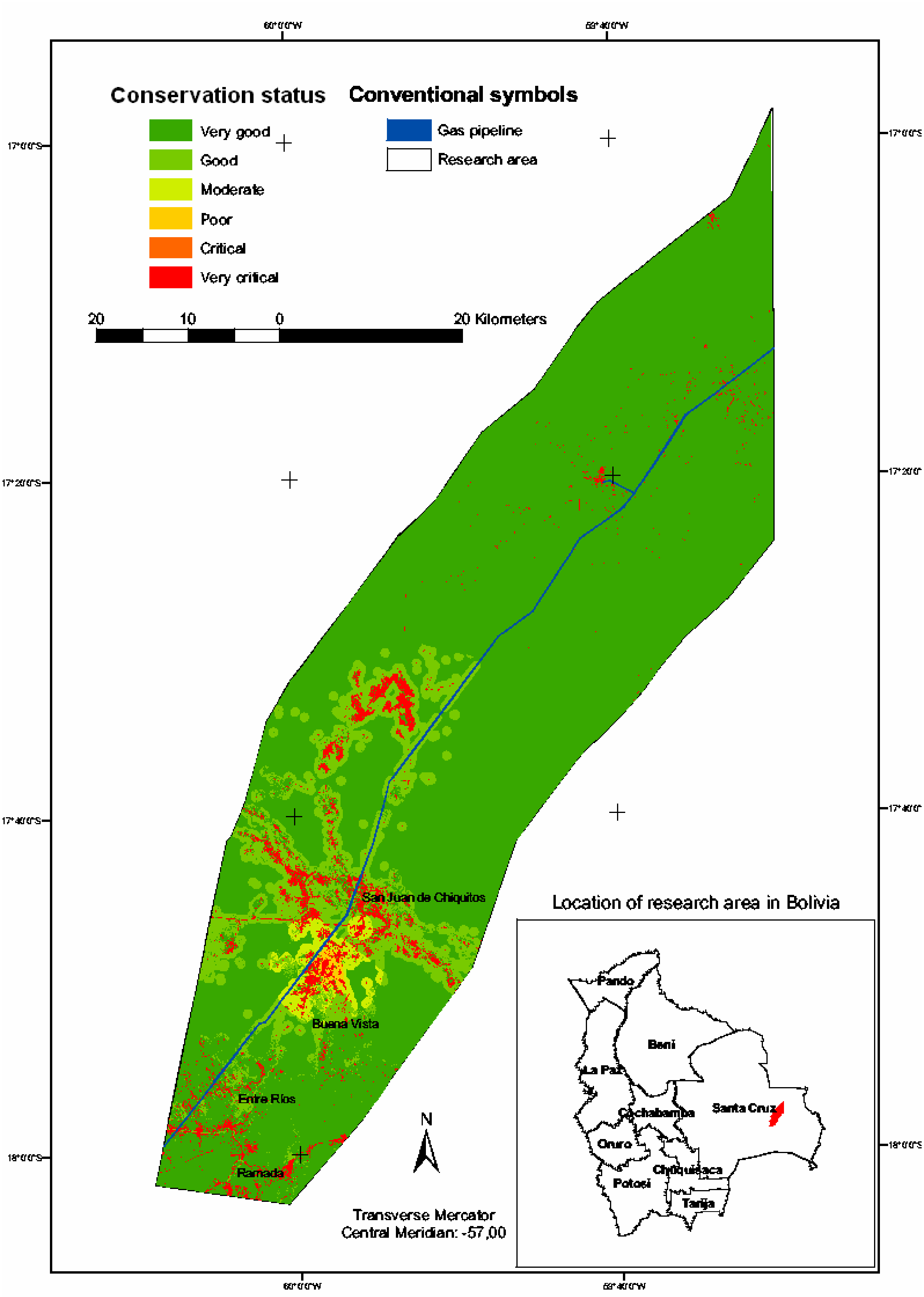


Figure 52 Conservation status map[60]



[60] See key to categories in Appendix XIV.

3.2.4 Brief monitoring and evaluation protocol

The following section describes the most important issues to consider when performing M&E tasks. The issues are arranged in three phases: (a) General arrangement, (b) Data collection, and (c) Processing and reporting of results. Recommended frequency of execution is every three or (maximum) four years. Table 35 shows general descriptions of indispensable M&E staff, as well as Table 36 the corresponding schedule. Depending on number of satellite images to analyze, the whole M&E process will take approximately 18 weeks. Total minimum budget will reach 13,463 Euro[61], with expenses and incomes calculated according to the Bolivian context (Table 35 and 37).

Table 35. M&E Personnel requirements

Staff member	Qualifications and experience required	Income per month (Euro)	Period required (weeks)	Total estimated income (Euro)
(a) Coordinator	Environmental scientist. Experience in social M&E activities, household interviewing and GIS. Knowledge of remote sensing and satellite image analysis. GPS skills.	1,000	11	2,750
(b) Field consultant	Agronomist, experience in agricultural extension and household interviewing. Dirt roads driving skills.	700	3	525
(c) Field consultant	One person of the villages, good communications skills, finished high school studies.	300	3	225
(d) Office consultant	Specialist in geo-informatics. Experience in satellite image analysis and GIS. Knowledge of ERDAS IMAGINE and ArcGIS 8.x or newer version.	800	7[62]	1,400
Total contracted services:				**4,900**

[61] 5,300 Euro correspond to software expenses.
[62] Time depends of number of satellite images to analyze. One image classification takes around 3 or 4 weeks.

Table 36. Staff schedule

Staff member	**M&E Phases and weeks**																	
	A				**B**			**C**										
	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18
(a) Coordinator																		
(b) Field consultant																		
(c) Field consultant																		
(d) Office consultant																		

3.2.4.1 Phase (a) General organization

The general organization is the responsibility of the *coordinator***,** who guides the overall M&E implementation and related activities. It will take approximately 4 weeks to perform this phase. Coordinator's main responsibilities and tasks are as follows:

- M&E management
- Ensuring the accomplishment of M&E according to the other components (see sections 3.2.1, 3.2.2, and 3.2.3).
- Recruit other M&E staff; undertake necessary training, guide, and supervision.
- Acquisition of supplies needed for phase (b) and (c).
- Administrative account and reporting.
- Prepare reports on M&E results.

Table 37. Main equipment required

	Line Item	Expense (Euro)	M&E Phase
Travel			
	Car Rental	1,100	B
	Petrol	130	
	Lodging	340	
	2 Tents	158	
	3 Sleeping bags	240	
	Meals	100	
Supplies			
	Computer	700	A, B and C
	Aster 1B satellite images	45[63] (per image)	B and C
	GPS	300	B
	Consumable office supplies	100	A, B and C
	Sub-totals	**3,263[64]**	
Software			
	Erdas Imagine 8.6 or higher	4,000	C
	ArcGIS 8.x or higher (ArcView License)	1,300	C
	EMDS	Free	C
	Sub-totals	**5,300**	
	Total	**8,563**	

3.2.4.2 Phase (b) Data Collection

The interdisciplinary team, made up of the *coordinator* and both *field consultants,* is responsible for carrying out this phase. Similar to section 2.4.1, data collection is obtained from *land cover data* and *village survey*.

3.2.4.2.1 Land cover data

Satellite images should be acquired before carrying out the village survey, as it should be validated on field. Using a GPS unit field reference points will be recorded matching the land cover types described in section 3.2.1.4. Field reference points will be used for training sites selection during classification of satellite images.

Data acquisition

[63] Expense depends of number of required images; *Aster* has only a 60km swath width compared to Landsat 's 180km.
[64] Calculated on the basis of 17 days.

Because Landsat 7 ETM+ failed between June and December 2003, data after January 2004 have errors that limit their scientific value. As proposed alternative for satellite images is the data the acquisition of Aster 1B (registered radiance at the sensor V003). *Aster* does not provide continuous coverage of the Earth. These data are collected only when ordered; therefore all requests must be performed at least 30 days in advance of the requested acquisition date. Detailed information for data order can be found under following URL: http://delenn.gsfc.nasa.gov/ims-bin/pub/nph-ims.cgi?endform=1&u=47367&sid=1122047367%2D19849&nextmode=MAINSRCH&submode=DEFAULT&mode=PREPARE&JS=1

3.2.4.2.2 Village survey

The village survey will take approximately 17 days, assuming the absence of unexpected events, e.g. car damage, streets blockade (very common kind of public protest in Bolivia), etc. Main tasks to perform during the village survey are:

- Interviews with leaders of PDI cattle groups,
- Household interviews,
- Field validation of satellite images.

To carry out the household and PDI cattle groups' interviews, the following standardized questionnaires (see Tables 38 and 39) should be used to collect current data. As far as possible, all households should be interviewed.

Table 38. Questionnaire for interviews with leaders of PDI cattle groups

ENCUESTAS PARA JEFES DE MÓDULOS GANADEROS DEL PDI	**Nombre de la Comunidad:**
Total módulos de la comunidad	________
Nombre del módulo	________
1) ¿Cuántas cabezas de ganado tiene su módulo en total?	________
2) ¿Cuántos miembros tiene su módulo?	________
3) ¿Cuántas hectáreas de pasto sembró este año su módulo?	________
4) ¿Cuántas hectáreas de pasto tiene su grupo en total?	________
5) ¿Dónde pastorea el ganado del modulo?	potrero____ campo_____monte____

Table 39. Questionnaire for household interviews

	Nombre de la Comunidad:
Datos personales del jefe del hogar	
1) ¿Cuál es su nombre?	________
2) ¿Cuántos años tiene usted?	________
3) ¿Cuántos años de escuela pasó?	________
4) ¿Cuántas personas viven en su casa?	________
Datos sobre empleo	
5) ¿A parte de su chaco, ¿trabaja Ud. en otro lado?	no___ si___
6) ¿Dónde trabaja Ud.?	________
7) ¿Cuántos meses al año?	________
Datos sobre el chaco	
8) ¿Me puede nombrar los 4 cultivos más importantes que ha cosechado este año?	
9) ¿Cuántos kilos de (______________________) ha cosechado este año?	

8) Nombre cultivo:	**9) Cantidad en kilos:**

10) ¿Ha vendido alguno de esos?	no___ si___
11) ¿Cuántos kilos pudo vender?	
12) ¿Dónde los vendió?	

Nombre cultivo vendido:	**11) Kilos vendidos:**	**12) Lugar de venta:**

13) ¿Ud. guarda su semilla para la siguiente siembra?	no___ si___
14) ¿Ud. utiliza semilla certificada?	no___ si___
15) ¿Usa químicos para la siembra?	no___ si___
16) ¿Cómo se llama?	________
17) ¿Usa químicos para plagas?	no___ si___
18) ¿Cómo se llama?	________
19) ¿Usted riega su chaco?	no___ si___
20) ¿Cuántas hectáreas riega?	________
21) ¿Hace descansar su barbecho?	no___ si___
22) ¿Cuántos años deja descansar su barbecho antes de volver a chaquear en el mismo lugar?	________
Datos sobre corta de madera	
23) ¿Cuántas troncas para madera a sacado en las últimas cuatro semanas?	
24) ¿Qué palos cortó?	
25) ¿Qué con hizo esa madera?	

23) Cantidad troncas:	**24) Nombre árbol cortado**	**25) Uso dado**

Datos sobre ganado	
26) ¿Usted tiene ganado propio?	no___ si___
27) ¿Cuántas cabezas tiene?	________
28) ¿Dónde pastorea su ganado?	potrero_____ campo_____monte____
29) ¿Tiene potrero propio?	no___ si___
30) ¿Cuántas hectáreas tiene? (no PDI)	________

3.2.4.3 Phase (c) Processing and reporting of results

This phase is the responsibility of the *coordinator* and the *specialist in geo- informatics.* The *coordinator's main* tasks are:

- Supervision of data processing, and
- Reporting of results (conforming to section 3.2.3)

The *specialist in geo- informatics* is responsible for the processing of data corresponds. The main tasks are as follows:

- Village data processing (analogous to section 2.4.2.1)
  - Quantitative data: Descriptive statistics (frequencies, means, ratios, and percentages) should be computed according to section 3.2.1.
  - Spatial data: Baseline M&E vector data layers and related quantitative data ((a) village areas, (b) infrastructure (c) potential area of fuel wood collection, (d) potential area of logging, and (e) potential area of browsing) should be updated according to new field observations for subsequently analysis by means of knowledge-based models.
- Land cover data processing (analogous to section 2.4.2.2)
  - A subset corresponding to the baseline M&E area should be cut out of the satellite imagery; other pre-processing requirements will depend on the satellite image quality.
  - Extraction of thematic information of land cover classes defined in section 3.2.1.4 by performing a supervised classification (see section 2.4.2.2.2).
- Integration of data and data evaluation
  - After processing and updating all data sets, these should be integrated with a corresponding knowledge-based model using EMDS, as follows:
    - Village areas data layer with village- level knowledge-based model
    - Infrastructure, potential area of fuel wood collection, potential area of logging, potential area of browsing, and land cover data layer with meso-level knowledge-base model

- Each model should be run to perform the corresponding evaluation, i.e.:
  - Village-level knowledge-based model to determine the agricultural pressure on the surrounding forest.
  - Meso-level knowledge-base model to determine conservation status of ecosystems.
  - Partial evaluations could be performed to determine pressures of individual factors such as fuel wood pressure, cattle pressure, and logging pressure. This can be achieved by running corresponding dependency networks.

"After all, all models are wrong, but some may hopefully be useful to understand the process of deforestation, and help in addressing the problem"
David Kaimowitz and Arild Angelsen

4 Final considerations, conclusions and outlook

From the analysis of characteristics of the villages and the gas pipeline is possible to conclude that the indirect impacts of the gas pipeline San Miguel-Cuiabá on the Chiquitano Dry Forest are related to: (a) the village level compensation program (PDI), and (b) the use of the right of way as route of access into new forest areas, especially for hunting and logging activities. The PDI contributed, at least in a temporary fashion, to the improvement of the well-being of village inhabitants. The land entitlement component from the PDI stands out as a positive effect, due to several aspects. Circa 45%[65] of the Bolivian territory has unclear property rights; it is principally due to the fact that the administrative process of clarifying land tenure is very expensive and complex. Neither the villagers nor the villages are in a position to pay these expenses. Additionally, different studies demonstrated that deforestation in Latin America tends to be lower in areas with high land tenure security [Kaimowitz & Angelsen 1998]. Securing land rights strengthened the awareness of the communities and will most likely have a positive effect on forest conservation. However, the most important negative impacts on the Chiquitano Dry Forest (in the long-term) are directly related to other components of the PDI that were positive for the village inhabitants (in the short-term). Because they obtained once credits for the expansion of the agricultural lands and other agricultural inputs, at least 155ha were deforested in the research area. Likewise, increments in cattle farming were considerable and will keep increasing because animal reproduction has been taking place successfully. The PDI introduced the arrangement of pasture in communal blocks and strengthened the tendency of establishing pastures instead of fallowing the land. Such slow, but ever-growing agricultural expansion potentially causes ecosystem degradation in the long-term [Angelsen & Kaimowitz 2001a], [Kaimowitz & Angelsen 1998], [Wunder 2003].

[65] Own calculation based on data from [INRA 2002].

The results show an evident disconnection between GOB, ENRON and SHELL when making decisions. On the one hand, they agreed to create a program for the conservation of the Chiquitano Dry Forest that aims at the sustainable development in the region and the ecosystem's conservation in the long-term. But on the other hand, the consortium concurred to carry out some components of the PDI that promote deforestation and forest degradation. Probably because after much controversy over the gas pipeline construction crossing the forest, the company wanted to start working as soon as possible. Therefore the consortium accepted the demands of the villages (which perceived the companies' capacity to pay) without considering that their traditional form of land use is not compatible with a sustainable development. Considering the research area size, the indirect impacts of the gas pipeline on the Chiquitano Dry Forest seem to be small. However, there is no doubt of the vulnerability of the area. Long-term supervision is needed to provide early warning signs of subtle changes in land use, before there is any observable and/or measurable effect on land cover conditions. The combination of the gas pipeline issues with aspects of the endogenous land use requires a joint M&E program.

Regular acquisition of data is essential to execute M&E activities, but is not enough to draw conclusions concerning the state of the system under study. Developing frameworks for data interpretation is a key task towards achieving operational readiness. Knowledge-based models are suitable frameworks that present several advantages: (a) permit the incorporation of evaluation arguments against which information is to be assessed; (b) the integration of information from different scientific disciplines, knowledge and experience from experts; and (c) represent a valuable tool for the transfer of knowledge and technology [Reynolds 2001], [Reynolds *et al.* 2003]. The monitoring and evaluation system results show that all these advantages are present in the developed M&E system. The arrangement of the selected indicators within knowledge-based models capitalizes on the information that they provide. Instead of constituting a list of 17 relevant indicators, their relationships are established in a concrete, logic and transparent way. The knowledge-based models add great value to be able to perform a sound evaluation of the criteria. Moreover, the arrangement of the indicators into two models considering their area of influence enables a more accurate spatial assessment. Because the M&E system shows early signals of change in land use (as proxy measure for the ecosystems' conservation status), the system constitutes a link with the end-users (FCBC) for ecosystem protection, and sets up the basis to assist them in the formulation of locally adapted resource management strategies. A fundamental point regarding implementation in the long-term is that the M&E system is capable of adapting to change. The modular character of the knowledge-base models facilitates their adaptation or expansion, e.g., if new human activities take place within the research area. Likewise, single parts of each model can also be transferred to other models in order to perform equivalent assessment in forest ecosystems exposed to similar human pressures.

Being based on scientific knowledge and characteristics of the local land use in the research area, the M&E system offers high level of robustness. "It is futile to measure complex biological systems merely to indicate the extent of human-induced disturbance, as the latter can usually be measured more directly" [Loyn & McAlpine 2001]: 394. Doing research on indicators implies the assumption that indicators are not intended to provide exact statements on the behavior of complex systems. They should aim at the provision of rapid and cost-effective information, and the indicator systems should stress relevance over precision [Prabhu *et al.* 2001]. The selected indicators are as simple as possible. Nevertheless, there are also some limitations in the *meso-level knowledge-based model.* Because timber extraction is to some degree an illegal activity, logging pressure is very difficult to evaluate. Accurate information about the location of logging does not exist for the research area; most significant logging activities are being carried out in areas without legal permission, but in the most accessible areas. Indicator 13 *potential area of logging* attempts to define the location of logging activities; it includes the most accessible forests with profitable timber, i.e. closed canopy forest bordering deforested areas in a radius of 0.5 km. This indicator is quite general; the *potential area of logging* is probably more extended than the actual area of logging. On the other hand, there are other minor areas that are being neglected by this indicator. Such areas are classified as open canopy forest, but are located just between closed canopy forest and deforested areas. They almost surely correspond to former closed canopy areas where selective logging activities have been taking place to a degree that the canopy is becoming more open. Further research is needed to refine this indicator. Likewise, indicator 14 *number of logged trees monthly* presents some bias: (a) it does not include trees killed or damaged during harvesting operations; (b) because of the illegality most lumberjacks will surely provide biased information on the actual number of logged trees; (c) outsider lumberjacks are not part of the interviewed sample. Nevertheless, and because the evaluation of the logging pressure is performed through a fuzzy node averaging all indicators, the weaknesses of each indicator are mutually balanced, i.e. if one indicator is overvalued and simultaneously another indicator is undervalued, the result is a legitimate mean value. Additionally, the fuzzy logic improves this average, because the result is not a resounding statement but a degree of truth. This is a good example of the advantages of using knowledge-based modeling, where the importance of identifying nodes and nodal interactions, by defining their relationships, reduces the focus on individual indicators [Prabhu *et al.* 2001].

Concerning hunting, its level of pressure is very important regarding the status of conservation of an ecosystem exposed to such influence. Nevertheless, all indicators related to it were excluded from the models, because of the lacking of fauna inventories. No adequate reference conditions were available for data evaluation. This situation hinders the implementation of this topic within the system. Fauna inventories should be performed to establish the size of the populations. Similarly, aspects related to climate and soils were not included in the M&E system because of (a) climate data are poor, no meteorological stations are within the research area, and the nearest stations are outlying, and (b) soil information is also poor, the inclusion of soil surveys within the M&E system is not cost effective. “One of the greatest constraints to the development of practical indicators is the demands they impose on data collection” [Finegan *et al.* 2001]: 387. The data collection phase of the M&E system takes only 3 weeks. In fact, the whole M&E process (from general organization to result reporting) takes around 5 months. The total costs (without considering software) amount to approximately 8,000 Euros. Taking into account the time and financial costs, performing the M&E every three or four years is feasible.

Development in the context of an information system is the process in which such system is designed for the user’s requirements, implemented, tested, and made ready for operation [Partridge & Hussain 1995]. The M&E system is an understandable and logic output that also considers and documents lessons learned on the field. These characteristics should facilitate successful acceptability and implementation by the end-user. The results of this research project provide a structured program for monitoring and evaluating the ecosystem conservation status in the research area. The system should assist decision makers in the formulation of locally adapted management strategies for conservation of the ecosystem. The level of pressure from each factor can be assessed separately, identifying which human activity is causing higher impact on the ecosystem. Likewise, scenarios can be also produced using the knowledge-based models.

Deciding which protection measures should be taken is a task that corresponds to the end-user. The M&E system is the basis for problem identification and analysis, the development of decision models will help the end-user in the design, evaluation, and selection of alternatives. The development of decision models involves multidisciplinary teams for research and execution, EMDS incorporates also the Criterium DecisionPlus application that supports the design and selection of alternatives for decision making (see Reynolds 2005). The development of a decision model for the research area poses the challenge of facing a careful design of measures to control the expansion of deforestation and forest degradation; it will be useful for several tropical countries. Performing this task should give special attention when incorporating new agricultural technologies (see Angelsen & Kaimowitz 2001a: 9-10). Similarly, the decision model should consider measures dealing with possible increments in the pressure of logging, due to reduction of transport costs by the future asphalting of the main road to Brazil[66]. The fuzzy logic knowledge-based M&E system presented here, establishes the basis for a decision-support system for the influence area of the gas-pipeline San Miguel-Cuiabá.

[66] (Santa Cruz - Puerto Suarez Corridor).

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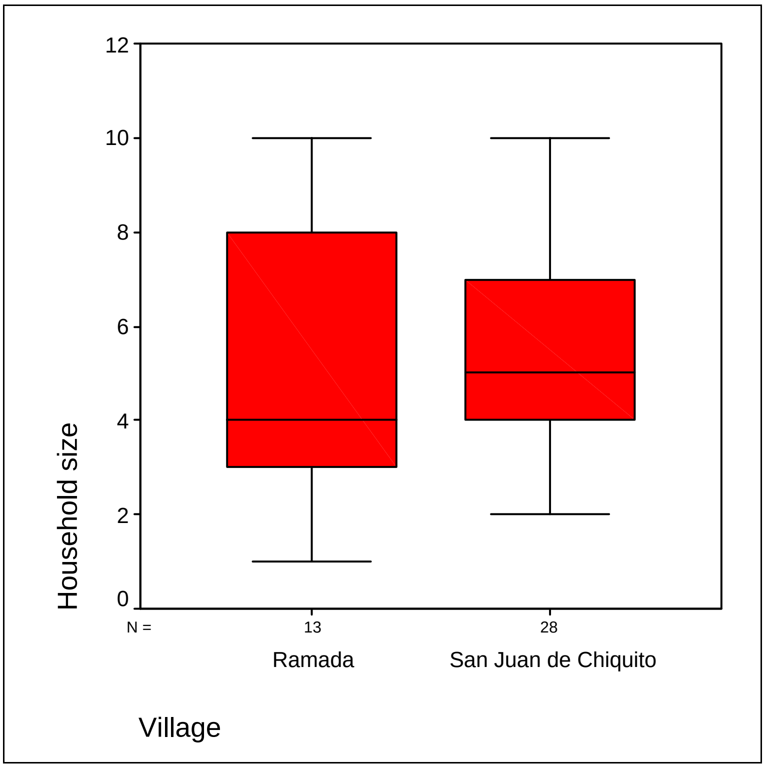
Appendix

Appendix I Indicators excluded from knowledge-based models

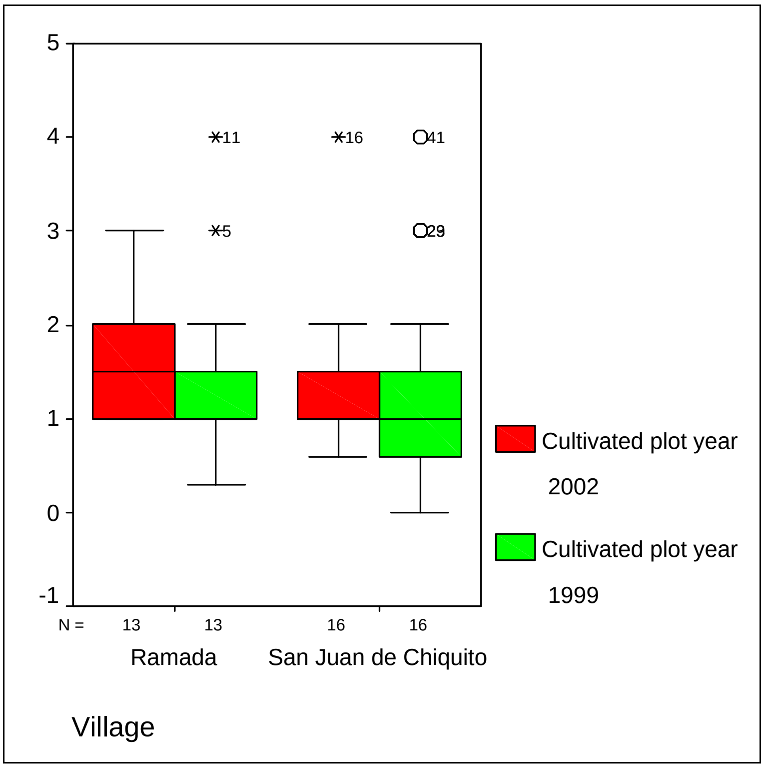
Indicator description	Reason for indicator exclusion
Period of fallow	Replaced by indicator *Percentage of households not practicing fallow*.
Type of fertilizer used	Inconsistent. Replaced by sub-indicator: Percentage of households using agrochemicals.
Kg of cash crops	Low explanatory power. Replaced by indicator *Proportion of commercialized farm produce.*
Number of cows	Inconsistent and redundant. Replaced by indicator *Number of browsing cattle*
Number of PDI's cows	Inconsistent and redundant. Replaced by indicator *Number of browsing cattle*
Area of pastures	Incorporated to the factor intensification of agriculture
Location of new settlement approved by government	Low level of collection feasibility. Data regarding property rights are difficult to obtain from the providing Institution (INRA). INRA worries about the misuse of information to encourage colorization of wastelands.
Distance to all-year road	Inconsistent and incompatible with modeling approach. Replaced by indicator *Average traveling speed on all-year road.*
Travel time to all year road	Inconsistent and incompatible with modeling approach. Replaced by indicator Average traveling *speed on all-year road.*
Amount of financial incentives from gas company for new clearing of forest	The PDI was a one-time donation; the possibility that GOB gives more credits is unlikely in the future.
Area of land with clear property rights	Inconsistent. Lack of specification for interpretation. Does not give information about the state of the ecosystem.
Size class distribution of human landscapes	Replaced by indicators *Deforested areas* and *Natural vegetation areas*.
Number of new breaches in the intersections of roads with the right of way	Too specific. Low explanatory power.
Number and localization of forest fires	Too specific. Lack of support from providing institution (BOLFOR).
Regeneration of vegetation at the edge of right of way	Too specific. Difficult to implement within the models.
Number of seed stock & shading trees per ha of agricultural lands	Too specific. Time- consuming.
mm precipitation	Too specific. Lack of data, there are no meteorological stations within the research area.
Number of new households	Replaced by indicator *Number of inhabited houses.*
Number of (male) household heads with permanent off-farm jobs	Replaced by indicator *Percentage of manpower with potential employment in logging*.
Number of animals consumed monthly Animal species consumed monthly Catch distance from villages	All indicators related to hunting were excluded because fauna inventories are lacking; i.e. no reference parameters were available for data evaluation.
Name of logged trees	Too specific. Replaced by indicator *Potential area of logging.*
Use of wood	Too imprecise. Replaced by indicator *Main use give to the timber*.

Appendix II The right of way

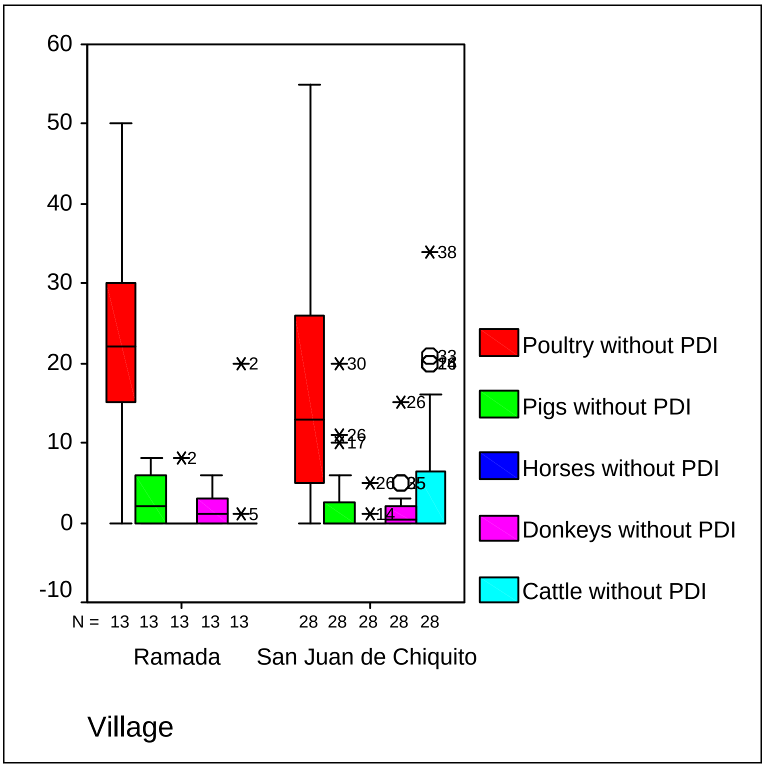
Appendix III Household size and personal characteristics of male household heads



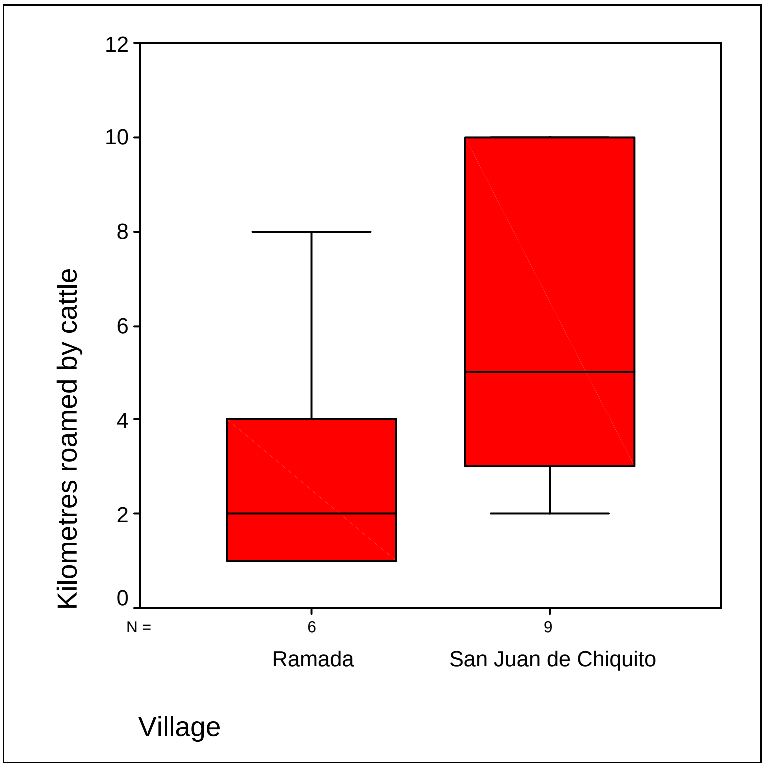
Appendix IV Cultivated area per household before and after PDI implementation (ha)



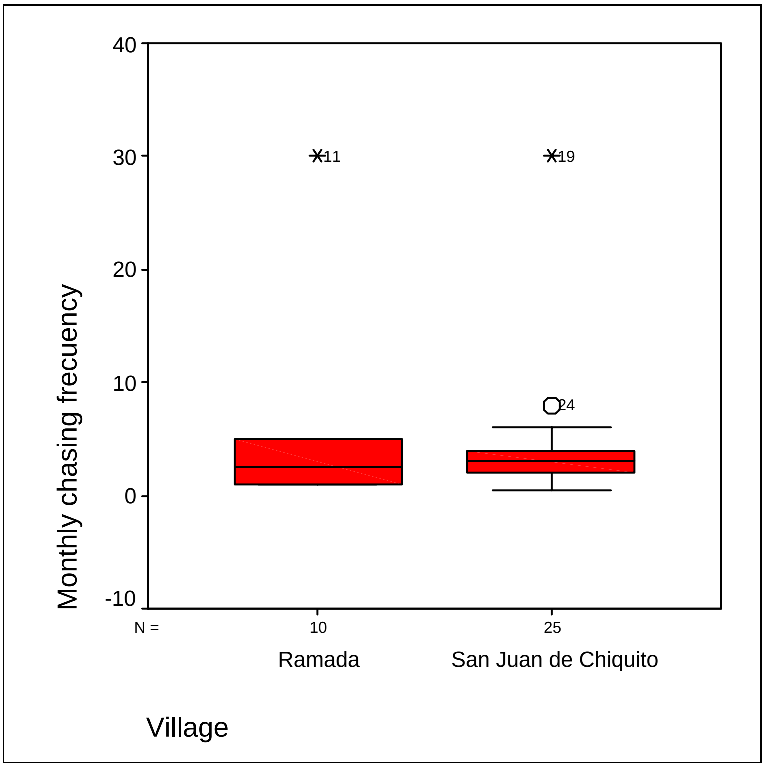
Appendix V Livestock owned per household



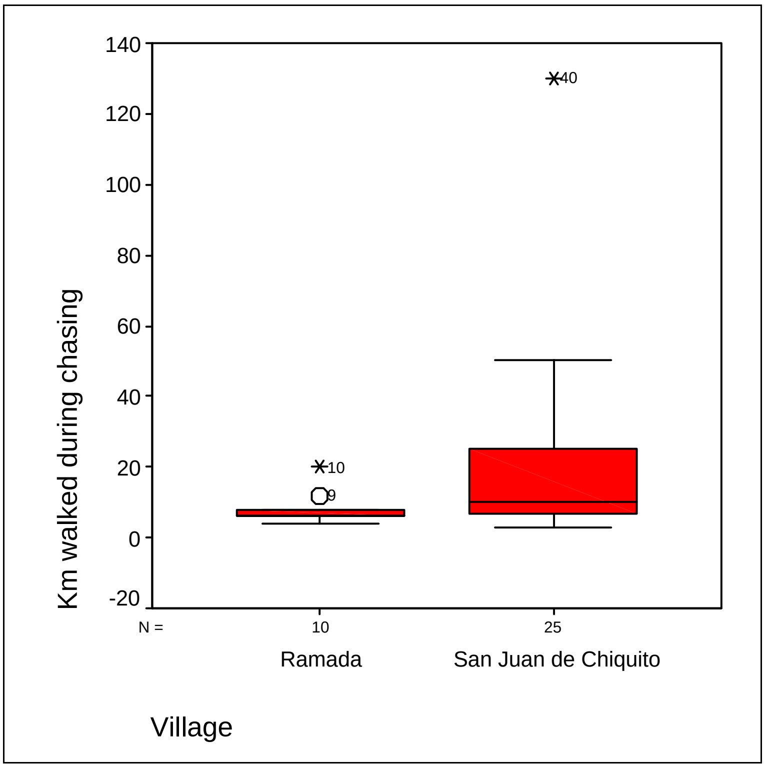
Appendix VI Distance roamed by cattle



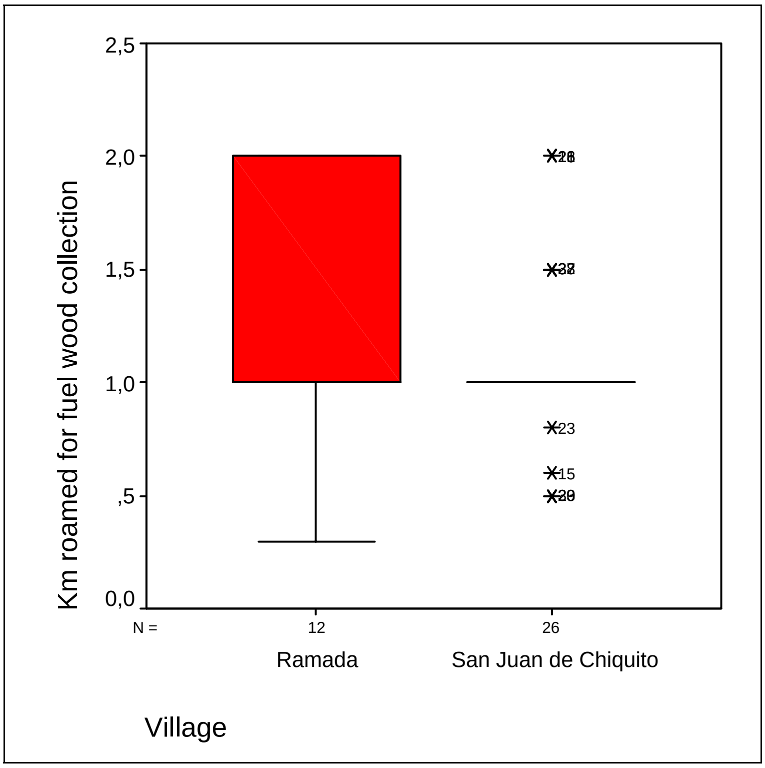
Appendix VII Monthly hunting frequency



Appendix VIII Km walked for hunting



Appendix IX Distance roamed for fuel wood collection



Appendix X Dbh harvesting limit permitted in the Chiquitano Dry Forest.

Tree specie	Cm
Swietenia macrophylla (mahogany)[67]	70
Cedrela spp. (cedar)	60
Hura crepitans (hura)	70
Amburana cearensis (oak)	50
Clarisia spp. (oiticica amarela)	45
Virola spp. (light virola)	45
Poeppigia procera (tasaá)	30
Anadenanthera sp. (curupay, vilca)	45
Calycophyllum multiflorum (verdolago)	45
Rest of species	40

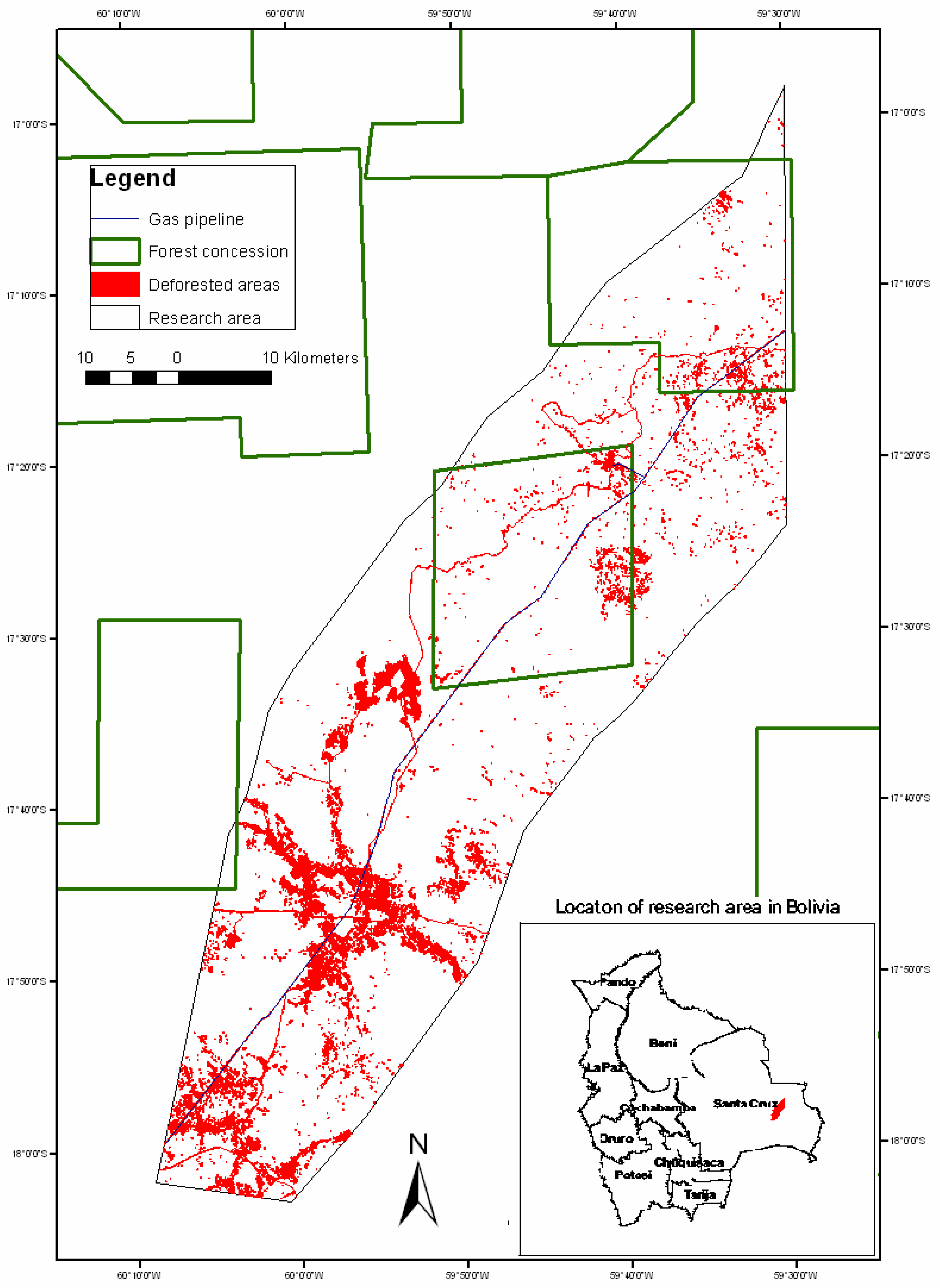
Source: Ministerio de Desarrollo Sostenible y Planificación & Superintendencia Forestal 1998

Appendix XI Estimated percentage of manpower with potential employment in logging

Village	Number	Per cent
Entre Rios	10	90.91
Ramada	12	93.34
San Juan de Chiquitos	22	82.23
Buena Vista	59	86.87

[67] Included in Appendix III of CITES

Appendix XII Comparison of areas of forest concessions with deforested areas



Source: Deforested areas from interpretation of Landsat ETM+ image by author. Gas pipeline and roads from [Céspedes *et al.* 2002] complemented by author. Forest concessions from [Columba, K. 2002].

Appendix XIII Key to categories of level of pressure

Level of use pressure	Fuzzy values
No support	-1.000 –-0.667
Very low	-0.666 – 0.333
Low	-0.332 – -0.000
Moderate	0.001 – 0.333
Strong	0.334 – 0.667
Very strong	0.668 – 1.000

Appendix XIV Key to categories of conservation status level

Conservation status level	Fuzzy values
Very good	-1.000 –-0.667
Good	-0.666 – 0.333
Moderate	-0.332 – -0.000
Poor	0.001 – 0.333
Critical	0.334 – 0.667
Very critical	0.668 – 1.000

Glossary

Agricultural intensification: The application of ever greater amounts of technology and labor techniques to increase productivity, i.e. higher input use or output per hectare. It refers to the growth in the complexity of the mode of production.

Boolean logic: Boolean logic is a form of algebra in which all values are reduced to either true or false.

Carrying capacity: number of species that a particular ecosystem can support without suffering irreversible deterioration.

Degree of truth: it denotes the extent to which a proposition is true. For example, in standard mathematics, the proposition zero belongs to the set {0} has a degree of truth of 1 (true), while proposition one belongs to the set {0} has a degree of truth of 0 (false). In fuzzy logic, the degree of truth of a proposition may be any real number between 0 and 1, inclusive. It is possible to build a fuzzy set F so that the proposition zero belongs to F and has a degree of truth of 1/2.

Dynamic link library (DLL): A library of program subroutines, which can be shared amongst several different application programs; a concept that is extensively used under Windows. Windows programmers do not have to re-invent the wheel each time they want to do something common such as undo the last command or highlight a line of text.

GPS (Global Positioning System): navigation system that works using worldwide networks of satellites.

Extension: provide additional GIS functionality in ESRI software. Most extensions are optional products that are registered or licensed individually.

Exogenous variable: a factor whose value is determined by factors or variables outside the causal system under study.

Evaluation argument: Threshold or measurement endpoints for indicators.

Heuristics: a method of solving problems by finding practical ways of dealing with them and learning from past experience.

Land cover: is the (bio-) physical ground cover of the land surface and immediate subsurface.

Land use: describes human employment of land surface and immediate subsurface.

Logic engine: Is the brain of expert and decision support systems. It is the module that does the actual logic, decision making and calculation to derive answers from a knowledge base. The logic engine provides the methodology for reasoning about the information contained in both, the database and knowledge base for formulating conclusions.

Metadata: information that describes features of another set of data

MERCOSUR: trade alliance between Argentina, Brazil, Paraguay, and Uruguay, with Chile and Bolivia as associate members.

Multispectral remote sensing: collection of reflected, emitted, or backscattered energy from an object or area of interest in multiple bands (regions) of the electromagnetic spectrum.

Node: Point used to connect two or more objects

Phased planting: parts of the plot producing the same crop or crop mixture are planted in a time sequence.

Pressure: human activities that exert a force on the environment and change its quality and the quantity of natural resources.

Radiant flux: amount of radiant energy onto, off, of, or through a surface per unit time, which is measured in *Watts*.

Radiometer An instrument that quantitatively measures electromagnetic radiation. Weather satellites carry radiometers to measure radiation from snow, ice, clouds, and bodies of water, the earth's surface, and the sun.

Right of way: legal permission to go onto or through another person's land. In this research path used for construction, operation and maintenance activities over the gas pipeline.

Rule: knowledge representation for use in making inferences as a human expert does.

Software architecture: The software architecture of a program or computing system is the structure or structures of the system, which comprise software elements, the externally visible properties of those elements, and the relationships among them.

Stakeholder: a large group of individuals and groups of individuals (including governmental and non-governmental institutions, traditional communities, universities, research institutions, development agencies and banks, donors, etc) with an interest or claim (whether stated or implied), which has the potential of being impacted by or having an impact on a given project and its objectives. Stakeholder groups that have a direct or indirect –stake- can be at the household, community, local, regional, national or international levels.

Training sites: Specific sites in the remotely sensed data that represent homogeneous examples of known land-cover types.

WRS (Worldwide Reference System): A global indexing scheme designed for the Landsat Program based on nominal scene centers defined by path and row coordinates.

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