DIPLOMARBEIT

Titel der Diplomarbeit

Land use, landscape configuration and live fences in an agricultural area in southern Costa Rica: proposals for improving landscape structure and establishment of biological corridors

angestrebter akademischer Grad

Magistra der Naturwissenschaften (Mag. rer.nat.)

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Wien, am 19 Jänner 2010

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Land use, landscape configuration and live fences in an agricultural area in southern Costa Rica: proposals for improving landscape structure and establishment of biological corridors

1. ABSTRACT

Biological corridors are essential for the structural connectivity of natural landscape elements across cultural areas, promoting migratory movements and genetic exchange of various plant and animal species. To assess the state of corridors within the agricultural area of La Gamba, Costa Rica, the land cover and land use, as well as linear landscape elements were investigated. The structure of the landscape was analyzed by means of landscape metrics. Linear elements were examined in terms of their structural parameters, whereas live fences were treated more in detail and characterized by their plant species compositions.

The current land use map clearly shows that pastures were most widespread, covering 61.07% of the agricultural area. Oil palm plantations, which comprised 30.55% of the agricultural area, were the second most important cultivation type. Over the last few years this type of land use had been spreading rapidly, as nearly half of the plantations (48.75%) were younger than three years. On the other hand, the production of rice had decreased rapidly. Rice plantations covered only 1.04% of the agricultural area. Hence, agricultural economy in La Gamba mostly based on cattle breeding and oil palm industry. Primary vegetation comprised 28.97% of the study area and secondary vegetation 35.49%. The intersection of the land use map with a digital elevation model illustrated that cultivations were mostly restricted to plain areas with inclinations lesser than 5°, while steeper slopes were mainly covered by primary forest. Landscape metrics illustrated that forest and rural areas clearly differed in their structure and that the generally big and compact shaped oil palm plantations have significantly influenced landscape structure. Furthermore, these plantations were scarcely bordered by live fences and provided fewer microhabitats than pastures.

The main purpose of live fences in La Gamba is to divide pastures and to restrict cattle movement. Consequently, they were found more frequently in pasture dominated parts of the study area. Most of them were very narrow (mean width 3.71 m) and poorly structured. Compared to natural line elements their ecological value was rather low. 46.57% of the live fences were linked to other connecting line elements, but only 13.70% were linked to forests.

Moreover, plant diversity within individual live fences was low. In total 92 plant species were found in live fences, but the mean species number (vascular plants with stem diameter >1 cm within a 50 m long sections of a live fence) was only 9.0. The total species number ranged from two to 19 species per site. 21 (22.83%) species were definitely planted in live fences, most of them were trees. Only five species (5.43%) were neophytes. The most important trees were *Erythrina fusca* (Fabaceae), *Gliricidia sepium* (Fabaceae) and *Psidium guajava* (Myrtaceae). In 24 out of 54 investigated live fences *Erythrina fusca* (Fabaceae) was the dominant species. Based on their species composition, live fences were classified into five groups by means of cluster analysis. Two groups were characterized by E*rythrina fusca* (Fabaceae), one by *Gliricidia sepium* (Fabaceae) and another by *Tectona grandis* (Lamiaceae). The fifth group consisted of live fences dominated by several species.

In order to map and visualize potential corridor routes between the forest areas, least cost paths through the farmland were computed. In those landscape parts which are poor in live fences, additional corridor elements would have to be established to make the agricultural area pervious for wildlife. Moreover, existing live fences would need to be enlarged, broadend and stocked with more ecological valuable species to improve their function as wildlife corridors. The general objective of this work is to provide an inventory of land use and live fences of the study area and to make proposals for improving the present situation.

Keywords: Biodiversity conservation, Costa Rica, La Gamba, Land use, Landscape corridor, Landscape metrics, Live fence

ZUSAMMENFASSUNG

Biologische Korridore spielen eine wichtige Rolle für die Verbundenheit von natürlichen Landschaftselementen in Kulturlandschaften und unterstützen die Migration und den genetischen Austausch von Pflanzen- und Tierarten. Um die Situation von Korridorelementen in der Agrarlandschaft von La Gamba, Costa Rica zu beurteilen, wurden die Landbedeckung und Landnutzung sowie lineare Landschaftselemente untersucht. Die Landschaftsstruktur wurde mittels Landschaftsindices analysiert. Weiters wurden verschiedene Strukturparameter der Linienelemente erfasst, wobei lebende Zäune und Baumalleen ausführlicher behandelt und anhand ihrer Pflanzenarten charakterisiert wurden.

Die aktuelle Landnutzungskarte zeigt deutlich, dass Viehweiden mit 61.07% den flächenmäßig größten Anteil der Kulturlandschaft einnahmen. Ölpalmplantagen, welche 30.55% der bewirtschafteten Flächen beanspruchten, waren die zweitwichtigste Form der Landnutzung. Der Anbau von Ölpalmen hatte in den vergangenen Jahren stark zugenommen, da mehr als die Hälfte der Plantagen (48.75%) jünger als drei Jahre waren. Andererseits ist die Produktion von Reis stark zurückgegangen. Reisfelder nahmen nur 1.04% der Agrarflächen ein. Folglich basierte die Landwirtschaft in La Gamba hauptsächlich auf Weidewirtschaft und dem Anbau von Ölpalmen. Primärvegetation nahem 28.97% des Untersuchungsgebietes ein, Sekundärvegetation 35.49%. Die Verschneidung der Landnutzungskarte mit einem digitalen Höhenmodell zeigte, dass die kultivierten Flächen auf flache Bereiche mit Neigungen von weniger als 5° beschränkt waren, während steilere Bereiche hauptsächlich mit Wald bedeckt waren. Die Landschaftsindizes zeigten deutlich, dass sich Wald- und Siedlungsflächen in ihrer Struktur unterschieden und dass die üblicherweise großen und kompakten Ölpalmplantagen die Landschaftsstruktur beeinflussen. Zudem waren die Plantagen selten von lebenden Zäunen begrenzt und boten weniger Mikrohabitate als Weideflächen.

Der Hauptzweck von lebenden Zäunen in La Gamba ist die Unterteilung von Weideflächen und die Einzäunung von Weidevieh. Demzufolge waren sie häufiger in den von Weiden dominierten Teilen des Untersuchungsgebietes zu finden. Der Großteil der lebenden Zäune war sehr schmal (mittlere Breite 3.71 m) und wenig strukturiert. Im Vergleich zu natürlichen linearen Landschaftselementen war ihr ökologischer Wert eher gering. 46.75% der lebenden Zäune waren mit anderen natürlichen Linienelementen verbunden, aber nur 13.70% schlossen direkt an Wald an. Zudem war die Pflanzendiversität innerhalb der einzelnen lebenden Zäune gering. Insgesamt wurden 92 Pflanzenarten in lebenden Zäunen gefunden, die mittlere Anzahl an Arten (Gefäßpflanzen mit Stammdurchmesser >1 cm innerhalb eines 50 m langes Abschnitt eines lebenden Zaunes) lag jedoch nur bei 9.0 und die Gesamtzahl an Arten reichte von zwei bis 19 Arten pro Untersuchungseinheit. 21 (22.83%) Arten, die meisten davon Bäume, wurden definitiv gepflanzt. Nur fünf Arten (5.43%) waren Neophyten. Die wichtigsten Bäume waren *Erythrina fusca* (Fabaceae), *Gliricidia sepium* (Fabaceae) und *Psidium guajava* (Myrtaceae). In 24 von 54 untersuchten lebenden Zäunen war *Erythrina fusca* (Fabaceae) die dominierende Baumart. Basierend auf ihrer Artengarnitur wurden die untersuchten Zäune mittels Clusteranalyse in fünf Gruppen unterteilt. In zwei dieser Gruppen war *Erythrina fusca* (Fabaceae) die dominante Baumart, in einer Gruppe *Gliricidia sepium* (Fabaceae) und in einer weiteren Gruppe *Tectona grandis* (Lamiaceae). Die fünfte Gruppe umfasste lebende Zäune die durch mehrere Arten charakterisiert wurden.

Um potentielle Korridorrouten zwischen den Waldflächen zu definieren und zu visualisieren wurden „least cost paths“ durch die Kulturlandschaft berechnet. In Landschaftsteilen, in denen lebende Zäune selten waren, müssten zusätzliche Korridorelemene errichtet werden, um die Agrarlandschaft für Wildtiere passierbar zu machen. Zudem sollten existierende Zäune verlängern, verbreitert und mit ökologisch wertvollen Baumarten ausgestattet werden, um ihre Funktion als Wildtierkorridore zu verbessern. Das Ziel dieser Arbeit ist die Bestandesaufnahme der Landnutzung und der lebenden Zäune im Untersuchungsgebiet und ein Ausblick auf Verbesserungen der aktuellen Situation.

RESUMEN

Los corredores biológicos son sistemas valiosos para la conectividad fisica entre hábitats naturales y permitan la migration y el intercambio genético de diversas especies vegetales y zoológicas. Para estimar la condición de los corredores en la zona agrícola de communidad de La Gamba en la zona sur de Costa Rica, fueron investigados los parámetros de cobertura y el uso del suelo, así como elementos del paisaje lineales. La estructura del paisaje fue analizada por índices de paisaje. Los elementos lineales del paisaje fueron examinados con respecto a parametros estructurales, en donde las cercas vivas fueron tratadas más en detalle y fueron characterizadas por la composición de plantas.

El mapa del uso del suelo muestra evidentemente que los pastizales son el uso más importante, cubriendo 61.07% del área agrícola. Plantaciones de palma africana, occuparon 30.55% del área agrícola, siendo el segundo uso más importante. La producción de este cultivo aumentó rápido, ya que casi la mitad de las plantaciones estudiadas (48.75%) fueron menores a tres años. Por otro lado, la producción de arroz decrecío mucho. Campos de arroz ocuparon solamente 1.04% del área agrícola. Por eso, la agricultura en La Gamba se basó en ganadería y plantaciones de palma africana principalmente. 28.97% del área de investigacion esuvieron cubriendo de vegetación primaria, 35.49% de vegetación secundaria. La combinación del mapa del suelo con un mapa del terreno mostró que la área agrícola estuvo limitada a áreas con menos de 5° de declive. Los índices de paisaje muestran que áreas de bosque y áreas cultivadas se diferencian evidentemente por su estructura y que las grandes y compactas plantaciones de palma africana afectaron la estructura del paisaje significante. Además, estas plantaciónes raramente lindaron con cercas vivas y ofrecieron menos micro-hábitates que pastos.

El objectivo principal de cercas vivas son la subdivisión de pastos y el cercado de ganado. Por eso, estuvieron más frequente en tierras de pastoreo en el área de estudio. La mayoría de las cercas vivas es muy estrecha (ancho medio 3.71 m) y mal estructurada. En comparación con elementos lineales del paisaje naturales su valor ecológico estuvó más bien bajo. 46.75% de las cercas vivas estuvieran lindantas con otros elementos lineales del paisaje, pero solamente 13.70% estuvieron lindantas con bosques. Además, la diversidad de plantas en cercas vivas solas estuvó baja. En total 92 especies de plantas estuvieron encontradas en cercas vivas, pero el número medio de especies (plantas vasculares con diámetro del tronco >1 cm dendo de una sección de 50 m longitud en una cerca viva) estuvó solamente 9.0 y el número total de especies por sitio de investigation varió entre dos y 19. 21 (22.83%) especies fueron plantadas definitivamente. Solamente cinco especies (5.43%) estuvieron plantas exóticas. Los árboles los más importantes fueron Poró (*Erythrina fusca*, Fabaceae), Madero negro (*Gliricidia sepium*, Fabaceae) y Guayaba (*Psidium guajava*, Myrtaceae). En 24 de 54 cercas vivas investigadas, la especie *Erythrina fusca* (Fabaceae) fue el árbol dominante. Por medio análisis clúster, de las cercas vivas fueron clasificadas en cinco grupos basándose en las composiciones de plantas. Dos grupos fueron caracterizados por E*rythrina fusca* (Fabaceae) como árbol dominante, un grupo por *Gliricidia sepium* (Fabaceae) y uno por *Tectona grandis* (Lamiaceae). El quinto grupo se compuso de cercas vivas dominadas por especies varias.

Al final de dibujar y visualizar corredores potenciales entre las áreas de bosque, “least cost paths” a través el campo estos fueron computados. En partes del paisaje donde hay pocas cercas vivas existieron, nuevos elementos conectados que deberían estar establecidos para hacer el campo transitable para animales salvajes. Así como, cercas vivas presentan deberían estar elongadas, ensanchadas y plantadas con especies de árboles de gran valor ecológico para lograr corredores funcionales. El fin general de este trabajo es de proveer un inventario del uso del campo y de las cercas vivas de la área de investigation y de hacer propuestas para mejorar la situtation actual.

2. INTRODUCTION

Nowadays biodiversity is highly threatened by human activities in all tropical regions of the world (KAPPELLE ET AL. 2003). Huge areas of tropical forests have been deforested to gain land for pastures and permanent cultures, which are often of enormous extent. This process is still going on and leading to the loss of natural ecosystems and biodiversity and to the fragmentation of forest areas. Currently, tropical forests cover 15% of the world land surface (FAO 2006). They store 25% of the terrestrial carbon and account for 33% of total terrestrial net primary production (BONAN 2008). Thus, the protection of remaining natural forests is essential for the conservation of ecosystem function and biodiversity. In non-protected areas, forests remnants are often so highly fragmented and scattered that they cannot provide adequate habitats for sensitive native plant and animal species. However, the problem of habitat fragmentation can be alleviated by improving the ecological connectivity between forest patches and natural landscape elements in agricultural areas (MORERA ET AL. 2005).

Biological corridors can be observed at different scales, from single landscape elements such as as hedgerows and live fences up to continental-scale corridors like the linkage at the Isthmus of Panama (BUREL AND BAUDRY 2003 p. 296). They are considered important landscape elements for wildlife conservation in open agricultural areas (e.g. FORMAN 1986 pp. 121-122 and 132-134, ROSENBERG ET AL. 1997, BEIER AND NOSS 1998, BUREL AND BAUDRY 2003 pp. 223-226 and 295-311, BUDOWSKI 2005, CHETKIEWICZ ET AL. 2006, SEAMAN AND SCHULZE 2009). Corridors connect patches of natural vegetation and increase the tree cover, which facilitates the movement of plants and animals and retains ecological processes (CHETKIEWICZ ET AL. 2006). Therefore, they can reduce the extinction risk of fragmented populations and favour the recolonization of unpopulated habitats. Interconnected populations, whose individuals can disperse between habitat patches, are usually more stable than isolated populations (BUREL AND BAUDRY 2003 p. 246). Further, corridors promote animal-plant interactions like pollination and fruit dispersal (TEWKSBURY ET AL. 2002). Habitat selection and movement of organisms determine how landscapes are used and are therefore a central point in identifying and evaluating corridors (ROSENBERG ET AL. 1997, CHETKIEWICZ ET AL. 2006, ESCOBEDO-MORALES AND MANDUJANO 2007, HARVEY ET AL. 2008b). So, it is essential to take into account landscape patterns and to include behavioral processes of the target organisms when applying corridors for wildlife conservation.

The conservation value of biological corridors has been discussed by many authors. Numerous studies have shown that for many species corridors enhance populations viability and are therefore a valuable conservation tool (e.g. BEIER AND NOSS 1998). On the other hand sceptics argue that corridors can contribute to the spreading of wildlife diseases (LYLES AND DOBSON 1993, HESS 1996, TABOR ET AL. 2001, BIENEN 2002) or may lure animals from good habitats into ecological traps or sinks where they suffer higher mortality (CHETKIEWICZ ET AL. 2006). These concerns definitely have to be considered when biological corridors are regarded as a conservation tool. Another critical point is that corridors should not be misused as a “cheap” alternative to other conservation strategies (BEIER AND NOSS 1998, BIENEN 2002, SEAMAN AND SCHULZE 2009).

In temperate regions the functions and patterns of hedgerows and windbreaks have been studied comprehensively and the ecological value of corridors for conservation purposes has been analysed in detail (e.g. FORMAN 1986 pp. 397-404, NDUBISI ET AL. 1995, ROSENBERG ET AL. 1997, GRILLMAYER ET AL. 2002, BUREL AND BAUDRY 2003 pp. 296-311). However, there are only few comparable studies on live fences in Central America (HARVEY ET AL. 2005). Live fences play an important role in agricultural landscapes in Central America, especially in pasture-dominated areas. In general, they are linear, straight landscape elements along property boundaries or adjacent to fields and pastures and mostly consist of one or few perennial plant species (BUDOWSKI 1987).

Generally, live fences are anthropogenic landscape elements with the purpose of separating grazing land into smaller paddocks, delineating properties and to restricting cattle movement. Traditionally, they are established by planting stem cuts of trees that easily produce adventitious roots. They are usually short, narrow, densely planted and species-poor. Nevertheless, live fences have a positive influence on agricultural landscapes because they increase the tree cover, connect natural landscape elements such as forest patches or riparian forests and provide habitat, shelter and food for wildlife. Thus, they contribute to the maintenance of landscape connectivity and raise habitat availability. Moreover, they are of considerable value for the farmers because they serve as a source of fodder, firewood, fruits and medical plants and are often cheaper than other fencing methods like electric fencing (HARVEY ET AL. 2005, CHACÓN LEÓN AND HARVEY 2007). Different studies on plants, birds and butterflies in the region of Monteverde in the north of Costa Rica showed that live fences were more species-rich than the adjacent agricultural areas (HARVEY ET AL. 2008a). The efficiency of live fences as biological corridors depends on their structure and plant species composition, which are mainly determined by their management and the climatic conditions.

Therefore, the characteristics of live fences can diverge substantially between different regions (HARVEY ET AL. 2005).

The protection and installation of biological corridors are important conservation instruments in Costa Rica. The institution SINAC (Sistema Nacional de Áreas de Conservación) is working on the conservation of biodiversity and natural resources in Costa Rica and has set up a national program "Programa Nacional de Corredores Biológicos de Costa Rica" (PNCB) for protecting biological corridors. The program arose from the initiative "Corredor Biológico Mesoamerícano en Costa Rica" andis supposed to be realized within a period of 5 years (2009-2014). The principles were laid down in the "Decreto Ejecutivo de la República NO. 33106 – MINAET" (May 30th 2006). The main objectives of PNCB are the conservation of the biodiversity and the restoration of the ecological connectivity between big forest areas. Furthermore, it intends to enhance the surrounding areas and support the collaboration of local actors and the relevant national institutions. Additionally, scientific work and monitoring programs concerning biological corridors in Costa Rica should be established and encouraged (SINAC 2009).

The village "La Gamba" is situated in the southwest of Costa Rica at the edge of the Piedras Blancas National Park. Hence, the agricultural area of La Gamba belongs to a zone that is important for the exchange of wildlife between forest areas. The village was founded in the mid 1940s by five families who lived on subsistance agriculture and hunting. Since that time land use has changed fundamentally. From 1938 to 1984 the United Fruit Company (U.F.Co.) possessed 4,000 ha of banana plantations in the Golfo Dulce Region, and from 1954 to 1961 bananas were the most common cash crop in La Gamba. In 1984, the company left precipitously causing a local crisis in the region which already suffered from a bad economic situation at national level. Many people became unemployed. Later on, former banana plantations were occupied by the inhabitants of the village and converted into rice fields and pastures. Since the 1950s public promotions had forced cattle breeding and large areas had been deforested to gain more pastureland. During the great depression in the 1980s many agricultural areas were abandoned, but rice fields and pastures still remained the most common forms of land use. Other crops such as cacao, yucca, banana, corn and grain never have been cultivated extensively since that time (KLINGLER 2007).

According to MORERA ET AL. (2005) the region is nowadays characterized by a dissection of farming activities resulting in a strong process of abandonment of fincas (small farms), and emigration of inhabitants. Mismanagement of land, mostly due to the lack of knowledge of sustainable farming, often causes degradation of soils. Various interrelated social and ecological projects (e.g. reforestation and alternative cultures) that were initiated by the Tropical Station La Gamba in cooperation with the local people are now intending to improve the economic situation of the farmers as well as the landscape structure (personal comment WEISSENHOFER 2009).

In contrast to the abandonment of fincas, the production of the African oil palm (*Elaeis guineensis* Jacq., Arecaceae) has been steadily rising since its introduction into the Golfo Dulce Region during the 1950s. In general, the production sites in Costa Rica are mainly concentrated on the wet Pacific coast where soils and climatic conditions are most suitable (CORLEY AND TINKER 2003). In La Gamba, oil palm industry was established relatively late (after 1995) due to the remote position of the village, but during the last decade many agricultural areas have been rapidly converted into oil palm plantations. By 2008 they had already become the second most area consuming land use type after pastures. This development profoundly affects the economic situation of La Gamba and has strong influence on the landscape structure.

This study intends to illustrate the changes and trends in land use and the resulting effects on the landscape pattern. For that reason, current land cover was mapped and different landscape metrics were calculated. It was particularly aimed to assess the ecological value of live fences in the study area La Gamba by investigating their structural characteristics and plant species compositions, thus providing a general overview of the current state of live fences. Additionally, potential corridor routes across the agricultural landscape were identified. This work shall form a basis for further investigations and action plans for biodiversity conservation, and offer applicable suggestions for improving their effectiveness.

3. STUDY AREA

3.1. Location and climate

The study area is situated in the southwest of Costa Rica in the Golfo Dulce Region and comprises the village La Gamba and its cultural area. La Gamba belongs to the district Golfito which lies within the Puntarenas Province. The investigated area borders the Piedras Blancas National Park (148 km²) in the west, the Fila Costeña in the northeast, the Río Esquinas in the north-west and the Golfo Dulce in the south (Fig. 1). After HOLDRIDGE (1971) the region includes three different life zones: "tropical rainforest", "tropical wetland forest" and "tropical premontane rainforest". The vegetation of the Piedras Blancas National Park and adjacent areas was investigated in detail by WEISSENHOFER ET AL. (2008a) who distinguished 16 types of primary and secondary vegetation and eight anthropogenic ecosystems.

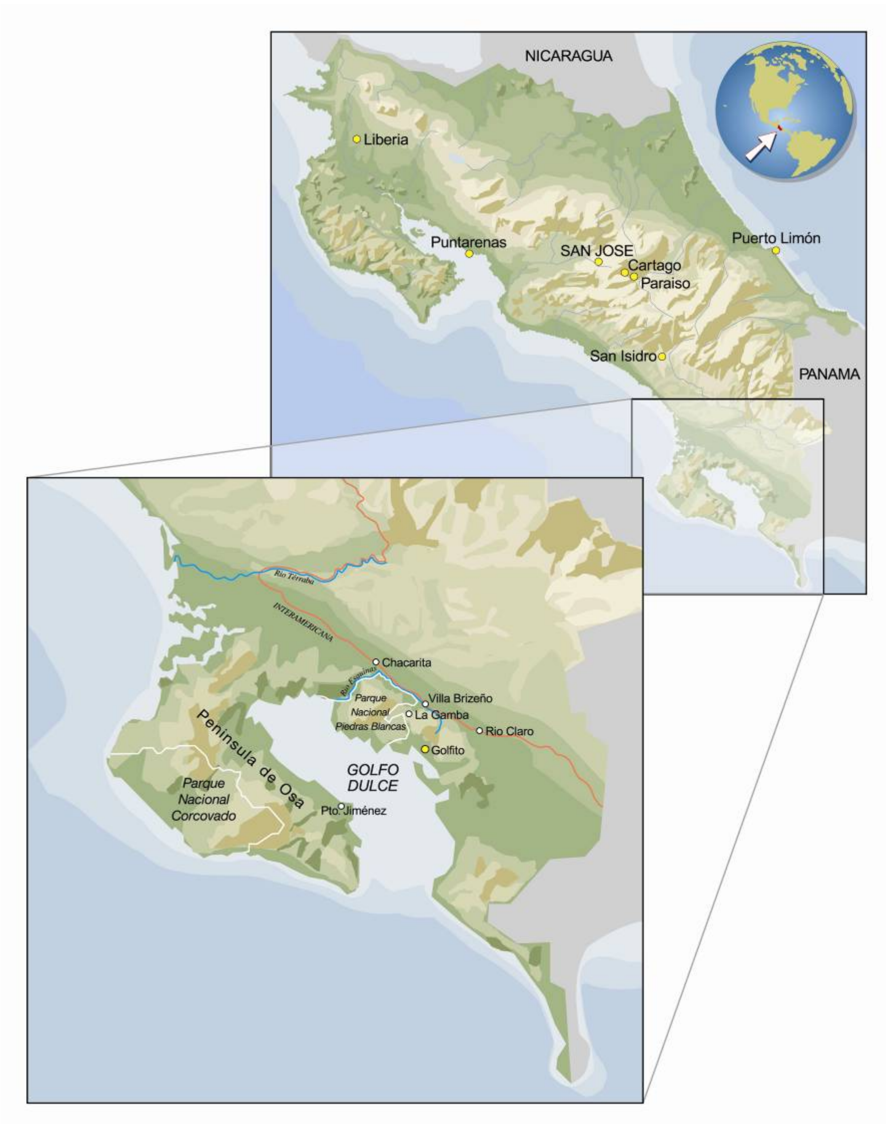

Figure 1: Map of Costa Rica and the Golfo Dulce Region. Adopted from WEBER ET AL. (2001).

From 1999 to 2007 the average annual precipitation measured at the Tropical Station La Gamba was 5.838 mm with heaviest rainfall from May to November. Average temperature was 28.2°C with an absolute minimum of 20°C recorded in August 1998 and an absolute maximum of 39°C in December 2001 (WEBER ET AL. 2001, WEISSENHOFER ET AL. 2008b).

3.2. Biodiversity and nature conservation in Costa Rica

Costa Rica is one of the most biodiverse countries in the world. Although it covers only 0.03% of the global surface (51,100 km² terrestrial surface) it harbors about 3.9% of the living species recorded on earth (KAPPELLE ET AL. 2003). Especially the Golfo Dulce Region (Fig. 1) has a particularly rich flora and fauna due to a very humid climate and diverse orographic formations. The ”tropical lowland wet forests” that cover most of the area are extremely high in plant species (HOLDRIDGE 1971). As in all other tropical regions of the world, biodiversity of the region is threatened by human activities. Before the arrival of the Spanish, 95% of Costa Rica was covered by dense natural forest. During the early stages of colonization relatively small areas of tropical forest were cleared for settlements and farmland. The rapid deforestation process was initiated in the 1950s by national policies that forced cattle breeding in order to increase meat exports (KAPPELLE ET AL. 2003). In 1977 still 42% of the national territory of Costa Rica was covered by natural forests, while in 1987 only 25% remained, leading to highly fragmented landscapes. This development strongly influences population dynamics and can cause a decrease or shifting of biodiversity (MORERA ET AL. 2007). Until today the situation has improved and many of the remaining natural forests are protected. In total, protected areas in Costa Rica cover 25.97% (13,271 km²) of the terrestrial national territory and 17.19% (5,208 km²) of the marine national territory (Tab. 1).

Table 1: Protected areas in Costa Rica (JIMÉNEZ AND GONZÁLEZ 2007).

Category	Number	Protected terrestrial areas (km²)	Percent of terrestrial national territory (51.100 km²)	Protected marine areas (km²)	Percent of marine national territory (30.308 km²)	Protected areas total (km²)
National Park	28	6,290	12.31%	4,756	15.69%	11,046
Biological Reserve	8	220	0.43%	52	0.17%	272
Protected Zone	31	1,577	3.09%	0	0.00%	1,577
Forest Reserve	9	2,163	4.23%	0	0.00%	2,163
National Reservation	71	2,368	4.63%	384	1.27%	2,752
Wetland	15	637	1.25%	0	0.00%	637
Others	4	16	0.03%	16	0.05%	32
TOTAL	**166**	**13,271**	**25.97%**	**5,208**	**17.19%**	**18,479**

4. METHODS

4.1. Field work

The field work in La Gamba was carried out from December 2008 to February 2009. The Tropical Station La Gamba was the starting point for the investigations and provided equipment for additional scientific work. The field work consisted of three main parts: A) Mapping of the current land cover and land use. B) Mapping of the linear landscape elements and investigation of their structural parameters. C) Investigation of species compositions in live fences ("cercas vivas") and roadside tree lines. Most of the areas of primary and secondary forest were adopted from the vegetation map of La Gamba (WEISSENHOFER ET AL. 2008a), unless the land cover had not changed. Some hardly accessible areas were classified using the vegetation map and a satellite image. All other areas were investigated in the field. For the investigation of plant species compositions of live fences, in total 54 sites were selected that were distributed more or less randomly over the study area. For each site along a section of 50 m all species of vascular plants with a trunk diameter of more than one centimeter were listed and the number of individuals counted. The reference to families follows APG III (2009). The positions of the investigation sites are provided in Appendix II (coordinates of the site centers). Other types of fences that did not consist of living plants ("cercas muertas" – dead fences) were not mapped.

4.2. Satellite image and maps

The base for the mapping of the region was a "QuickBird 2" satellite image with a pixel size of 2.4 m for the multispectral channels (green, blue, red and infrared) and 0.6 m for the panchromatic channel (La Gamba, Costa Rica, QuickBird scene 052017330010_01_P001, 6/12/2007 © Digital Globe (2008), WGS 1984, UTM Zone 17N, Distributed by Euroimage). The extend of the study area was 25.66 km² (8°41' to 8°43'N, 83°9' to 83°13'W) including the village and the surrounding agricultural areas as well as parts of primary and secondary forest. In addition, a digital elevation model of the region (source: CENIGA, Centro National de Información Geoambiental, Costa Rica) with a pixel size of 20 m was used for examining the distribution of land cover types over different elevations and slopes. As prearrangement for the field work, the study area was digitized (at a scale of 1:10,000) to produce a vector map that outlined homogenous areas. For this purpose the program ArcView® (ESRI, Inc., Redlands, CA) was used.

Furthermore, a shapefile showing the linear elements of the landscape (that could be outlined at a scale of 1:10,000) was created. To point out the spatial arrangement of the linear elements, they were added to the land cover map.

4.3. Land cover and line elements

To classify the landscape elements 27 categories of land cover and twelve categories of line elements were defined (Tab. 2 and 3) based on the vegetation map of La Gamba (WEISSENHOFER ET AL. 2008a) and earlier studies carried out in the region (KLINGLER 2007). The land cover categories were divided into three categories of ecosystem types: primary vegetation, secondary vegetation and anthropogenic ecosystems (after WEISSENHOFER ET AL. 2008a). While the natural vegetation types (primary vegetation) were not differentiated as detailed as in the vegetation map by WEISSENHOFER ET AL. (2008a), the anthropogenic ecosystems were split into more categories to get a finer illustration of the current land use. Oil palm plantations were distinguished in stands older and younger than three years for estimating the increase of cultivation area of this land use type. Five pasture sub-types were differentiated according to their tree cover (Tab. 2 and Fig. 2). Line elements were classified into connecting and cutting elements. The class of cutting elements includes rivers and rivulets because usually they are barriers for wildlife movement.

The 110 connecting line elements were examined in terms of the structural parameters length, width, height, vegetation layers, age distribution and vertical structure (age classes of perennial plants), canopy closure, adjacent land use, transition zone, dominance and species richness, number of interruptions and origin. Because of their very similar features, the parameters of live fences and roadside tree lines were joined and analyzed more in detail, regarding length, width, height, tree density and density of live fences (m per ha).

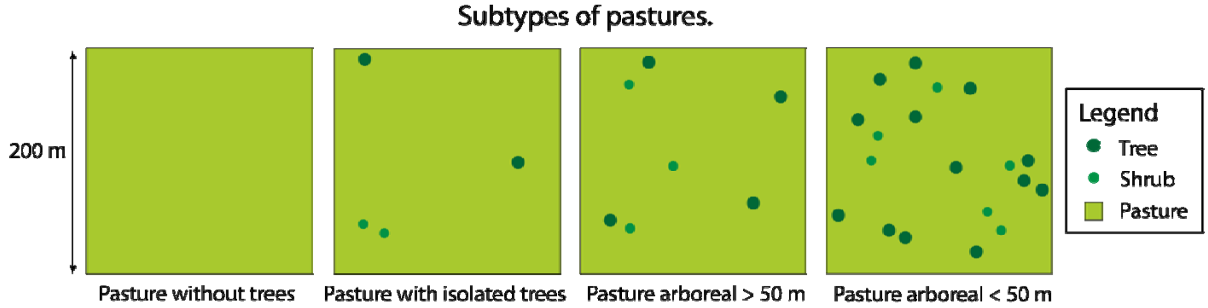

Figure 2: Illustration of the different pasture types. Design: HÖBINGER (2010). Source: KAPPELLE ET AL. (2003).

Table 2: Classification of the land cover types of the study area (based on WEISSENHOFER ET AL. 2008a).

LAND COVER TYPE	DESCRIPTION
Primary vegetation	
Primary forest [1]	Well structured and tall forests, generally with many native palms
Mature riparian forest [2]	Remnant forests growing along rivers, depending on streaming characteristics, more or less dynamic and structured
Pioneer riparian forest	Very dynamic and simply structured vegetation along rivers and gravel banks, dominated by pioneer species
Riparian vegetation dominated by *Gynerium sagittatum*	Very dynamic and poorly structured vegetation along rivers, dominated by *Gynerium sagittatum* P. Beauv. (Poaceae), very low diversity, even pure stands of *Gynerium sagittatum*
Secondary vegetation	
Old secondary forest	Relatively dense, moderately structured forests with canopy trees taller than 15 m, dense ground layer
Young secondary forest	Simply structured forests with canopy trees up to 15 m, dense ground layer
Forest patch	Compact remnants of primary or secondary forest within the agricultural area
Fern-dominated vegetation	Secondary vegetation dominated by *Dicranopteris pectinata* Willd. (Gleicheniaceae) on steep slopes or ridges and *Nephrolepis multiflora* (Roxb.) Jarrett & Morton (Oleandraceae) on flat and swampy areas
Charral	Transitional vegetation type between abandoned land and young secondary forest, more than 5 years out of use (MORERA ET AL. 2007), young trees and shrubs, vegetation height less than 10 m
Anthropogenic ecosystems	
Tacotal	Abandoned pasture with shrubs and small treelets, less than 5 years out of use, vegetation height less than 5 m (KAPPELLE ET AL. 2003)
Pasture arboreal >50 m	Pasture with trees, distance between individual trees more than 50 m
Pasture arboreal <50 m	Pasture with trees, distance between individual trees less than 50 m
Pasture with isolated trees	Pasture with scattered trees, distance between individual trees more than 100 m
Pasture without trees	Pasture, mostly on flat areas, no trees or shrubs
Oil palm <3 years	Young plantations of African oil palm *(Elaeis guineensis* Jaqc., Arecaceae*)*, mostly stemless
Oil palm >3 years	Old plantations of African oil palm *(Elaeis guineensis,* Arecaceae) , stem height mostly more than 0.5 m
Rice	Intense agricultural land with short-lived field crop
Corn	Intense agricultural land with short-lived field crop
Cacao	Permanent agricultural land used as cacao plantation
Banana	Permanent agricultural land used as banana plantation
Timber	Plantations of timber trees such as Melina = *Gmelina arborea (*Lamiacaeae), Teak = *Tectona grandis (*Lamiaceae) or *Terminalia amazonia* (Combretaceae)
Clearing	Cleared areas, prepared for temporal or permanent cultures
Residential area	Settlements, mostly small villages, fincas (farms) or single houses
Horticulture	Cultivated land within residential areas, gardens for growing ornamental plants, spices, herbs and fruit trees for domestic use

[1] Primary forest was not differentiated more in detail because this category was not investigated in the field and was not relevant for the analysis.

[2] Riparian forests were excluded from primary forests because they have a very different species composition and they are important natural landscape elements within agricultural areas.

Table 2 (continued)

LAND COVER TYPE	DESCRIPTION
Water	
River	Streaming water
Open water	Lakes and ponds

Table 3: Classification of the line elements (linear landscape elements) of the study area.

LINE ELEMENT	DESCRIPTION
Connecting elements	
Forest strip	Linear remnants of forests with more than three rows of trees and at least three vegetation layers
Riparian vegetation	± Natural riparian forests or vegetation along rivers
Live fence	Tree lines serving as property boundaries and for keeping cattle in or out of certain areas
Roadside tree line	Tree lines along roads and streets, also serving as fences and property boundaries
Hedgerow	Line elements serving as property boundaries, dominated by shrubs, no continuous tree layer
Cutting elements	
Street	Generally gravel roads, frequently used by cars
Path	Access roads to agricultural areas, mostly unpaved
River	Streaming water, rivers and little streams
Drainage ditch	Anthropogenic line elements for draining pastures, plantations or fields

4.4. Ecological value of line elements

Based on the recorded structural parameters, the connecting line elements were divided into three categories of "ecological value". Therefore, a simple point system was set up (Tab. 4). In this connection, the ecological value was regarded as the suitability of connecting line elements for serving as biological corridors. The origin types of line elements were adopted from FORMAN (1986, p. 124): introduced (anthropogenic landscape elements), disturbance (elements caused by natural or anthropogenic disturbances), regeneration (elements that result from regeneration processes), remnant (relicts of original vegetation) and resource (elements that result from very variable or extreme resource situations).

For every parameter of each line element one to three points were assigned (Tab. 4). According to the sum of points, each line was then assigned to one of the three categories. Category one represented lines with the lowest ecological value and category three the ones with the highest ecological value. The evaluation system refers to general principles of corridor ecology, but it is not based on any ecological studies on behavior and requirements of certain animal or plant species. Generally, wide and straight corridors are more effective than narrow and curved ones. Gaps and other interruptions decrease the quality of a corridor and limit the flow of organisms (FORMAN 1986 pp. 139-144 and 397-404, BAIER AND NOSS 1998, GRILLMAYER ET AL. 2002, BUREL AND BAUDRY 2003 pp. 298-299, HARVEY ET AL. 2005, CHETKIEWICZ ET AL. 2006).

Table 4: Evaluation system for the classification of connecting line elements into different categories of ecological value.

CRITERIA	CATEGORY 1	CATEGORY 2	CATEGORY 3
Ecological value	**Low**	**Medium**	**High**
Length	<100 m	100 m – 200 m	>200 m
Width	<5 m	5 m - 15 m	>15 m
Vegetation layers	One	Two	Three or more
Age distribution and vertical structure	homogenous or little structured	moderate to heterogeneous structured	heterogeneous structured
Canopy closure	Open	Gappy	Closed or dense
Adjacent land use	Settlement, Plantation, Temporal cultivation, Clearing	Pasture, Tacotal, Charral	Forest, Forest patch, Riparian forest or vegetation, Reforestation
Transition zone	<0.5 m	0.5 m – 2 m	>2 m
Dominance/ Species richness	Dominant species, low species richness	Abundant species, relatively rich in species	No dominance, species rich
Number of interruptions	Many	Single	None
Origin	Introduced or disturbance	Regeneration	Remnant or resource

This classification of line elements shall serve as orientation and overview for further studies and as an outline of the state and configuration of corridor elements within the study area, but it can not give species specific information on the "quality" of the line elements.

4.5. Statistics

4.5.1. Cluster analysis

For statistical analysis and graphics the program R version 2.6.0 (R DEVELOPMENT CORE TEAM 2007) was used. The cluster analysis on the data of the species inventory was performed by means of the K-means clustering algorithm (HARTIGAN AND WONG 1979). Therefore, the number of cluster centers has to be given (k). The observations are portioned into k groups such that the sum of squares from points to the assigned cluster centers are minimized (R DEVELOPMENT CORE TEAM 2007). Calculations were done with different numbers of cluster centers and without defining any cluster centers to detect the most appropriate number of groups. The appliance of five cluster centers led to a division of investigation sites into a maximum of clearly distinguishable groups.

4.5.2. Landscape metrics - Fragstats

To analyze the landscape pattern different landscape metrics were computed using the software FRAGSTATS 3.3 (MCGARIGAL AND MARKS 1995). For this purpose the number of land cover categories had to be reduced, because a too fine division of categories distorts the results. Additionally, all types of linear elements were assigned to one of the land cover categories and added to the land cover map (Tab. 5). The resulting map was converted to raster format with a grain of 2.4 m and divided into eight sections (Fig. 3). These were delineated in order to include at least five land cover categories each, to be of simple shape, and to represent relatively homogenous and characteristic zones of the landscape. The sections *Bolsa Forest, Bonito Forest* and *Station Forest* were "forest sections" mainly covered by primary and secondary forest. The sections *Bolsa, Bonito 1, Bonito 2, La Gamba* and *Station Agriculture* were "rural sections" for being agricultural areas with different cultivation types and only small forest patches.

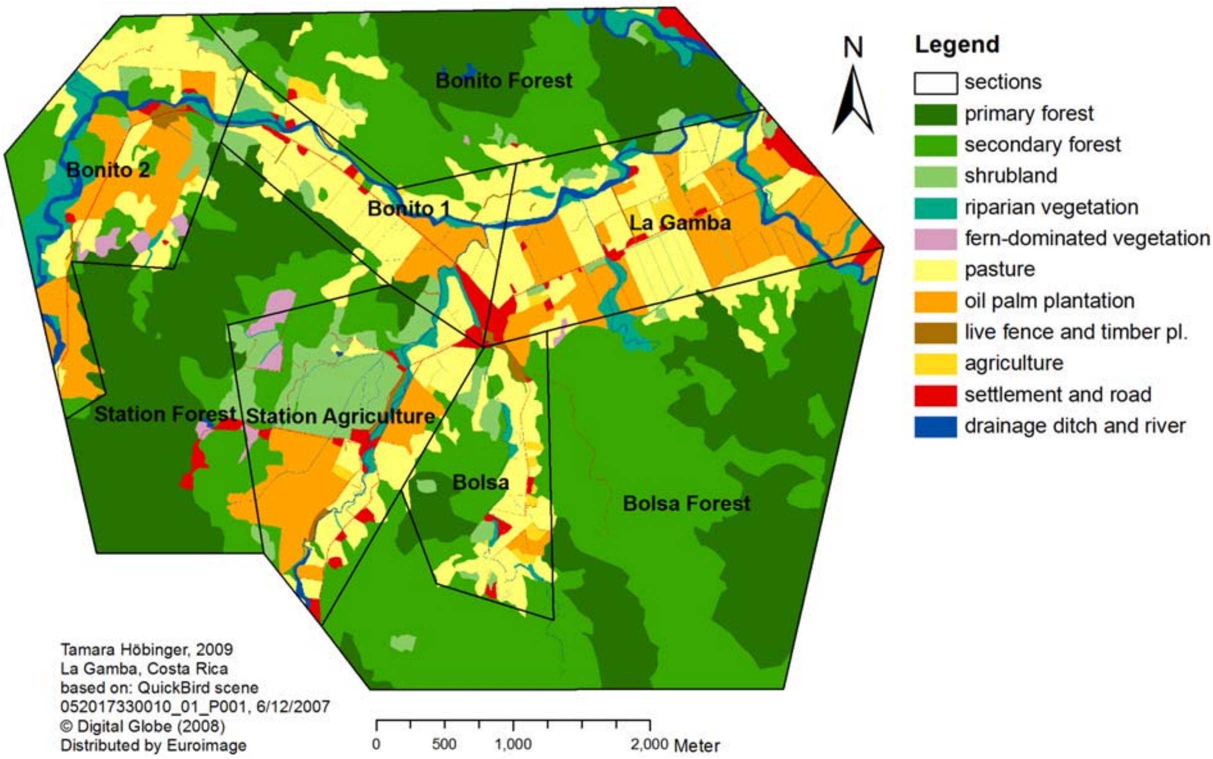

Figure 3: Land cover map and landscape sections used for the landscape pattern analysis.

For the computation of the landscape metrics the eight neighbor rule was applied to guarantee that linear landscape elements were identified as single patches (McGarigal and Marks 1995, Schindler et al. 2008). Only metrics standardized for area (e.g. patch density) were used as the landscape sections were of different size.

Table 5: Subsumption of land cover and linear element categories used for the landscape pattern analysis.

CATEGORY FOR FRAGSTATS	LAND COVER CATEGORY	LINE ELEMENT CATEGORY
PRIMARY FOREST	Primary forest	
SECONDARY FOREST	Old secondary forest Young secondary forest Forest patch	Forest strip
SHRUBLAND	Charral Tacotal	Hedgerow
RIPARIAN VEGETATION	Mature riparian forest Pioneer riparian forest Gynerium sagittatum dominated vegetation	Riparian vegetation
FERN-DOMINATED VEGETATION	Fern-dominated vegetation	
PASTURE	Pasture without trees Pasture with isolated trees Pasture arboreal >50 m Pasture arboreal <50 m	
OIL PALM PLANTATION	Oil palm >3 years Oil palm <3 years	
LIVE FENCE AND TIMBER PLANTATION	Timber	Live fence Roadside tree line
AGRICULTURE	Banana Corn Rice Cacao	
SETTLEMENT AND ROAD	Residential area Horticulture Clearing Others	Street Path Others
DRAINAGE DITCH AND RIVER	River Open water	River Rivulet Drainage ditch

In total eight metrics (Tab. 6) were selected according to the recommendations of other authors, who tested the correlations and performances of different landscape metrics (Botequilha Leitão et al. 2006, Cushman et al. 2008, Schindler et al. 2008). At landscape level the five metrics PD, PAFRAC, SIMI, CONTAG and PRD were chosen and at class level the four metrics AREA, PAFRAC, ENN and ECON. The aim was to choose a small set of uncorrelated metrics that illustrate different aspects of the landscape. The program FRAGSTATS computes landscape metrics at different levels. These are single patches, classes (land cover types) and the landscape as a whole. In this work the landscape structure at class and landscape level was investigated. At class level the metrics refer to the spatial pattern and configuration of single patch types (land cover types). At landscape level the metrics measure the spatial pattern of the entire landscape mosaic (McGarigal and Marks 1995). Several class and landscape level metrics are distribution statistics, i.e. they summarize the values of the single patches (e.g. mean, range, sd). In this study, the area-weigthed means (greater areas have greater influence on the index value) were used with exception of the mean patch area for which the simple arithmetic mean was preferred.

Table 6: Description of landscape metrics used in this study (after McGarigal and Marks 1995 and Schindler et al. 2008).

ACRONYM	METRIC NAME	DESCRIPTION
PD	Patch density	Number of patches per area (100 ha).
AREA	Patch Area	Size of the patches (ha).
PAFRAC	Fractal dimension	Shape index that measures the degree of complexity of planar shapes based on perimeter-area ratios. PAFRAC approaches 1 for very simple and 2 for very complex shapes.
ECON	Edge contrast	Ratio of contrast-weighted to non contrast weighted edge length per patch. The unit is percent and the metric approaches 100 when the contrast of the focal patch to its adjacent patches increases.
ENN	Euclidean Nearest Neighbor Distance	Minimum edge to edge distance (m) of one patch to its nearest patch of the same type. ENN approaches zero as the distance to the neighboring patch shrinks.
SIMI	Similarity index	Measures the similarity of neighboring patches. SIMI considers the size and proximity of all patches whose edges are within a specified search radius of the focal patch, weighted by their similarity.
CONTAG	Contagion index	Measure of the spatial aggregation and neighborhood relationships of patch types in percent. At class level CONTAG refers to the tendency of a single patch type to be aggregated, at landscape level it represents the degree of aggregation of all patch types.
PRD	Patch richness density	Number of patch types per 100 ha.

4.5.3. Computed corridor routes

In order to trace potential corridor routes between the main forest areas, resistance values (ranging from one to ten) were assigned to the land cover categories (Tab. 7). The resistance value represents the difficulty with which an individual of a species can move through a grid cell of the landscape. A high resistant value means a high barrier effect on plant and animal movement (Adriaensen et al. 2003, Beier et al. 2007). The resistance values were chosen empirically, decisive parameters for the assessment were naturalness and tree cover of the land cover types. The chosen values represent the permeability of the landscape for all organisms. If corridor routes for a specific plant or animal species have to be calculated, these values may not be correct and have to be adapted.

The resulting “resistance map” was transformed into raster format (GRID) with a pixel size of 2.4 m. The corridors were computed by means of the ArcGIS tool “cost path” which calculates the least-cost path between two given points within a landscape. Based on the resistance map and a “source layer” indicating the habitat patches, for each grid cell a “cost value” is computed which represents the distance to the source (ADRIAENSEN ET AL. 2003). In order to compute least cost paths between the forests of the study area, the start and end points of the corridors had to be set. In total 16 points were set within the forest areas, each with a distance of approximately 300 m to the forest edge. Between these points nine corridors, that crossed the agricultural area at different locations were computed (Fig. 10 and 17). The least cost paths were transformed from raster to vector format (polylines) and buffered, creating corridors zones with a width of 100 m.

Table 7: Resistance values of the land cover categories. High resistant values signify a high barrier effect.

Land cover type	Resistance value
Primary forest	1
Old secondary forest	2
Mature riparian forest	2
Young secondary forest	3
Pioneer riparian forest	3
Forest patch	4
Charral	4
Gynerium sagittatum	5
Tacotal	6
Timber	6
Pasture arboreal <50 m	7
Pasture arboreal >50 m	7
Oil palm >3 years	8
Pasture with isolated trees	8
Fern-dominated vegetation	8
Pasture without trees	9
Oil palm <3 years	9
Horticulture	9
Banana	9
Cacao	9
Residential area	10
Rice	10
Corn	10
Clearing	10
River	10
Open water	10

5. RESULTS

5.1. Land use

5.1.1. Land cover categories

The study area (25.66 km²) represents a rural area in the south of Costa Rica and comprises most of the cultivated land of the village La Gamba and parts of the surrounding forests. It includes natural, semi-natural and anthropogenic ecosystems. The village is situated in the center of the study area (Fig. 4). Its agricultural area mainly extends along the river plains of the region. The Piedras Blancas National Park is situated in the south-west of the Tropical Station.

Table 8: Total area and percentage of each land cover category of the study area.

Land use category	Area [ha]	Area [%]
PRIMARY VEGETATION	**743.40**	**28.97**
Primary forest	667.63	26.02
Mature riparian forest	59.15	2.31
Gynerium sagittatum	8.65	0.34
Pioneer riparian forest	7.97	0.31
SECONDARY VEGETATION	**910.79**	**35.49**
Old secondary forest	483.40	18.84
Young secondary forest	366.78	14.29
Charral	34.66	1.35
Fern-dominated vegetation	18.56	0.72
Forest patch	7.38	0.29
ANTHROPOGENIC ECOSYSTEMS	**869.84**	**33.90**
Oil palm >3 years	136.20	5.31
Pasture without trees	130.46	5.08
Oil palm <3 years	129.53	5.05
Pasture with isolated trees	120.19	4.68
Pasture arboreal <50 m	108.82	4.24
Tacotal	98.20	3.83
Pasture arboreal >50 m	73.50	2.86
Residential area	35.09	1.37
Rice	9.07	0.35
Timber	8.89	0.35
Horticulture	7.60	0.30
Banana	3.37	0.13
Others	3.08	0.12
Corn	2.94	0.11
Cacao	1.97	0.08
Clearing	0.93	0.04
WATER	**42.19**	**1.64**
River	40.54	1.58
Open water	1.64	0.06
TOTAL	**2,566.21**	**100.00**

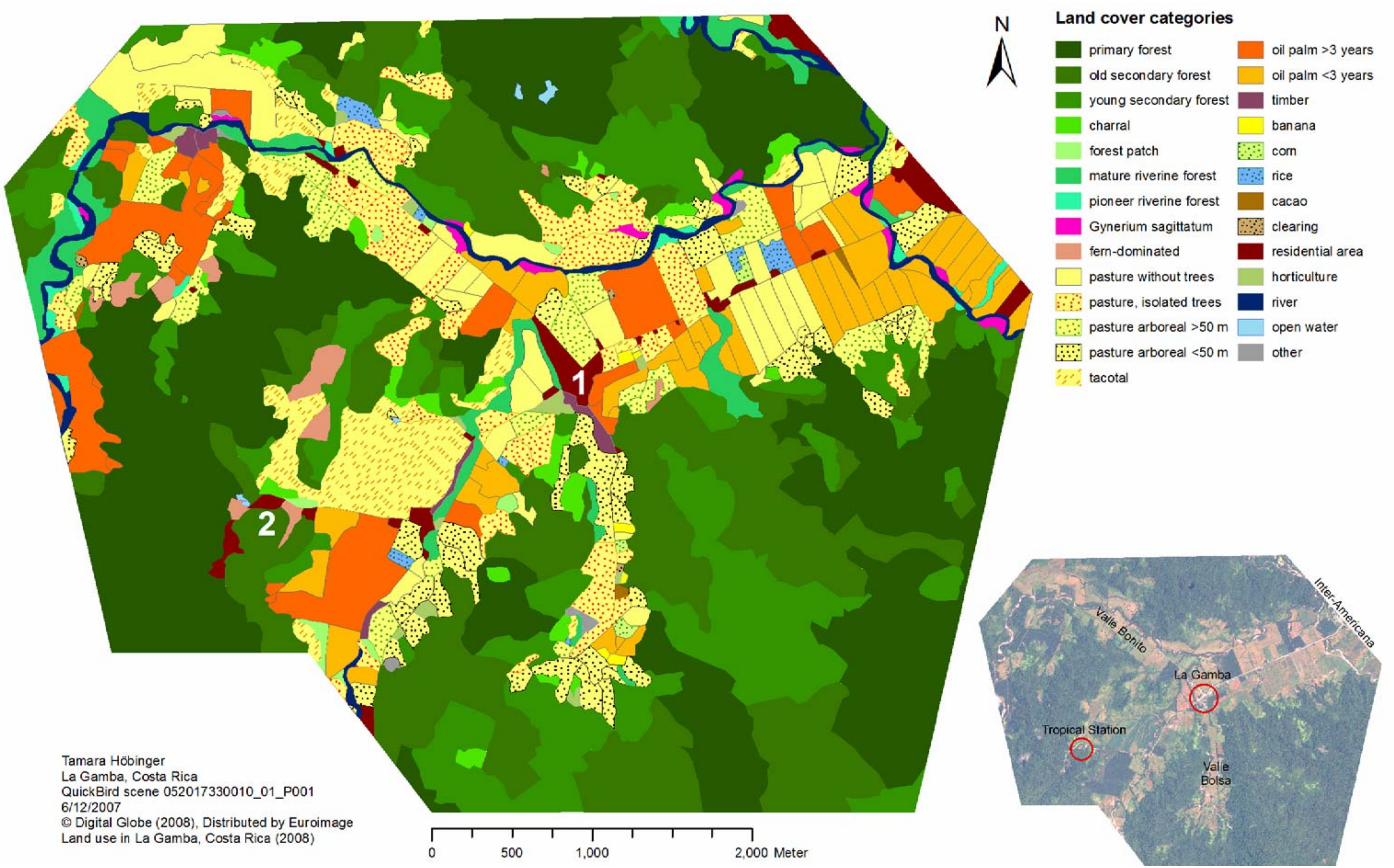

Figure 4: Land cover map of La Gamba, Costa Rica (2008). 1 = Village La Gamba, 2 = Tropical Station.

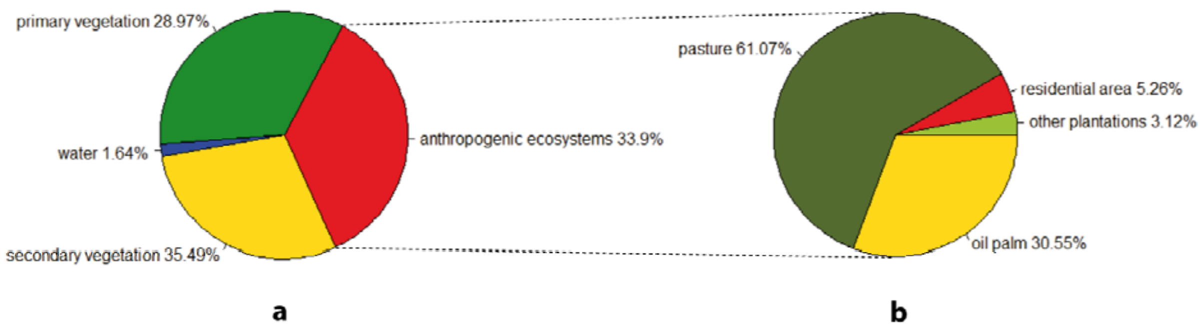

Figure 5: Area portions of ecosystems and land use types - a) in percent of the total study area (25.66 km²) and b) in percent of the anthropogenic ecosystems (8.70 km²).

Conspicuously, the three main ecosystem types (primary vegetation, secondary vegetation and anthropogenic ecosystems) comprised almost equal parts. In relation to the total study area (25.66 km²) 28.97% of the surface were covered by primary vegetation, 35.49% by secondary vegetation, 33.90% by anthropogenic ecosystems and 1.64% by water (Tab. 8 and Fig. 5). The proportion of primary vegetation was surprisingly high, as the outline of the study area was chosen in order to cover mostly agricultural area. In total 61.76% of the landscape were covered by forest of which 26.02% (of the total study area) belonged to primary forest, 18.84% to old secondary forest, 14.29% to young secondary forest and 2.62% to riparian forest. All other categories of primary and secondary vegetation covered relatively small areas.

Pastures were the most area consuming land use type (Tab. 8 and 9 and Fig. 4) comprising 61.07% of the agricultural area (20.69% of the total area). The proportions of the different pasture types were more or less balanced with a coverage of 15.00% pasture without trees, 13.82% pasture with isolated trees, 12.51% pasture arboreal <50 m, 11.29% tacotal and 8.45% pasture arboreal >50 m. The second most extensive land use type were oil palm plantations which comprised 30.55% of the agricultural area (10.36% of the total area). Remarkably, 14.89% of the agricultural area (5.05% of the total area) were plantations younger than three years which means that about 50% of the oil palms were planted during the last three years, mostly at the expense of pastures and rice fields. Interestingly, most of the new plantations were established close to the Interamericana (Pan-American Highway) and to the village La Gamba. In general, oil palm plantations were mostly located near to the main roads of the region, whereas pastures were also present in less accessible areas. In contrast to oil palm plantations, the cultivation of rice decreased sharply during the last years. Only 1.04% of the agricultural area (0.35% of the total area) were used as rice fields because many have been converted into pastures or oil palm plantations. All other cultivation types comprised very small areas since crops like bananas, corn and cacao were mainly planted for private use only.

Table 9: Land use categories (ha and %) of the agricultural area.

Land use category	Area [ha]	Area [%]
PASTURE	**531.17**	**61.07**
Pasture without trees	130.46	15.00
Pasture with isolated trees	120.19	13.82
Pasture arboreal <50 m	108.82	12.51
Tacotal	98.20	11.29
Pasture arboreal >50 m	73.50	8.45
OIL PALM	**265.72**	**30.55**
Oil palm >3 years	136.20	15.66
Oil palm <3 years	129.53	14.89
OTHER PLANTATIONS	**27.17**	**3.12**
Rice	9.07	1.04
Banana	3.37	0.39
Corn	2.94	0.34
Cacao	1.97	0.23
Timber	8.89	1.02
Clearing	0.93	0.11
RESIDENTIAL AREA	**45.77**	**5.26**
Residential area	35.09	4.03
Horticulture	7.60	0.87
Others	3.08	0.35
TOTAL	**869.84**	**100.00**

Inclination and land use

Agricultural areas were strongly associated to the steepness of the land surface. The inclination of the study area reached from 0° to 48°. The altitudes ranged from 60 m (valleys) to 345 m above see level with the highest points in the forest southeast of La Gamba. The intersection of the land cover map with a digital elevation model (Fig. 6) evidently illustrates that farmland and settlements were restricted to plain areas which correspond exactly to the river plains of the Río Bonito, Quebrada Gamba and Quebrada Bolsa. More than 90% of all oil palm plantations and more than 80% of pastures and the other cultivated areas were found at inlinations of less than 5°, which covered 46.25% of the total area (Tab. 10). Apart from the river plains some small fincas and pastures were also found in forested areas at low inclinations. In contrast, only 24.5% of primary vegetation occurred at inclinations of less than 5°, while areas with steeper slopes were mostly covered with natural vegetation. Primary and secondary vegetation were nearly equal in their distribution patterns over different inclination categories.

Only small areas of cultivated land were found at slopes steeper than 5° (Tab. 10). These were mostly abandoned and arboreal pastures and parts of oil palm plantations. In the Valle Bonito an oil palm plantation was found on relatively steep slopes (5° to 20°). Parts of pastures and plantations were even present at inclinations up to 37°. Rice and corn fields occurred up to 15° and banana plantations up to 18°. Slopes steeper than 38° were solely covered with forest. On the other hand, only small areas of low inclination were not used as farmland due to bad or swampy soil conditions or bad accessibility. Thus, most of the wet lowland rainforests on plain areas and natural riverside vegetation already got lost in the region. Forested plain areas were usually remnant riparian forests and secondary forests on land parts that have been formerly used as pastures.

Table 10: Land use categories (%) per inclination category.

Land use category	0° - 5°	6° - 10°	11° - 20°	21° - 30°	31° - 40°	41° - 50°
Primary vegetation	24.5	14.1	32.0	21.8	7.2	0.4
Secondary vegetation	23.5	13.1	31.4	23.7	7.8	0.5
Pasture	83.0	4.4	6.8	4.2	1.6	0.0
Oil palm	93.9	1.7	3.0	1.0	0.4	0.0
Other plantations	86.9	5.4	4.6	2.2	0.8	0.0
Residential area	83.9	8.4	4.6	2.9	0.0	0.0
Total area	46.3	10.1	22.3	15.8	5.2	0.3

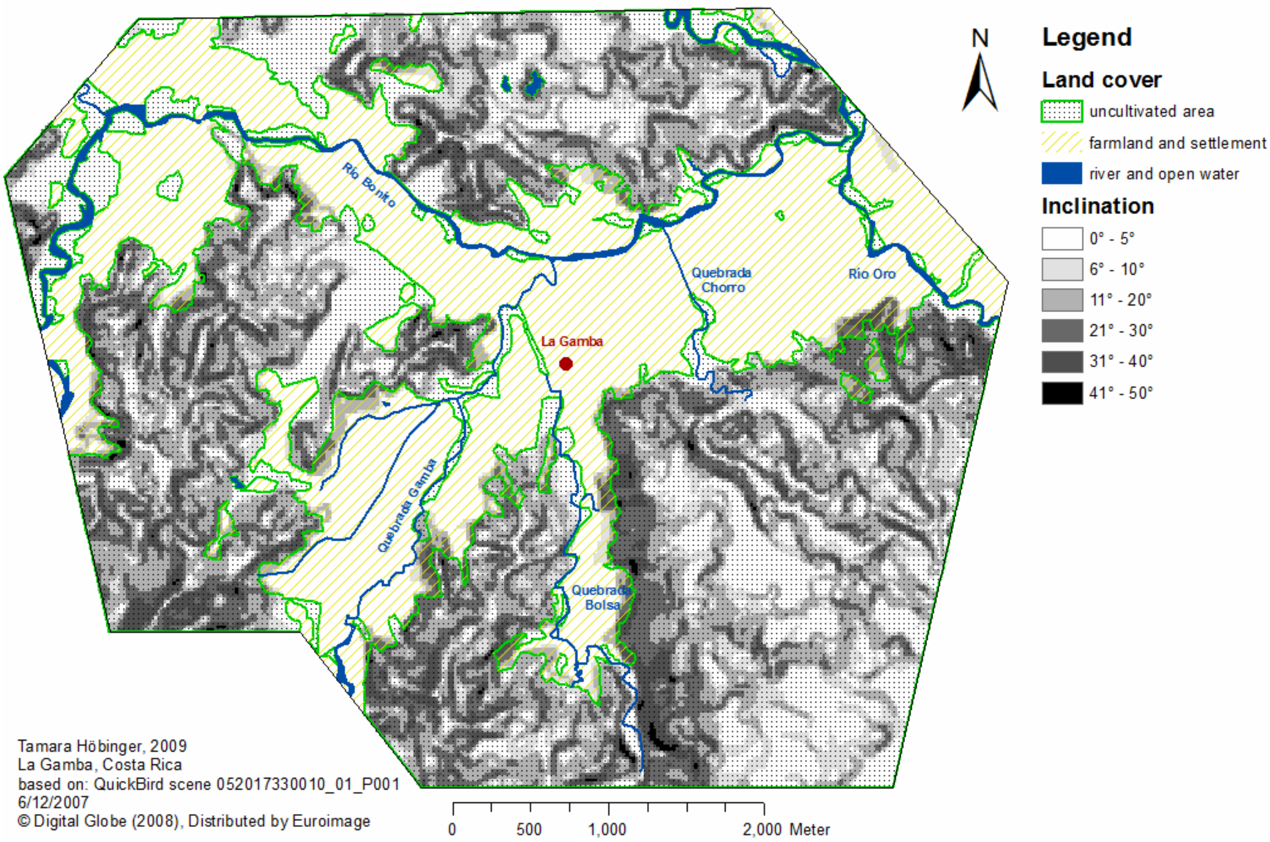

Figure 6: Relation of land cover and inclination within the study area.

5.1.2. Landscape metrics

a. Characterization of forest and rural areas (landscape level)

All landscape level metrics (but particularly PD, SIMI and CONTAG) uncovered large differences between forest and rural areas regarding their landscape structure (Fig. 7).

Patch density (PD): Forest sections had low values of PD ranging from 15.16 to 47.36, whereas rural sections showed high values ranging from 64.77 to 236.69 which means that they consisted of more smaller patches. The sections *Bolsa forest* and *Station forest* showed the lowest values of PD as they were mainly covered by primary and secondary forest. In contrast, the section *Bonito forest* was characterized by a relatively high PD of 47.36 because it included some pastures, a part of the river Río Bonito and riparian vegetation. Conversely, the rural section *Bonito 2* had a low PD of 64.77 compared to the other rural sections due to oil palm plantations and pastures of great extend in this area. The highest PD (236.69 patches per 100 ha) was found in the rural section *Bonito 1*.

Fractal dimension (PAFRAC): Interestingly, the fractal dimensions of all sections were low with values ranging from 1.10 to 1.32. Fractal dimensions of forest sections reached from 1.10 to 1.18 which means that the patches in these section were very simple shaped. The values of rural sections were higher ranging from 1.15 to 1.32. The lowest fractal dimension of rural sections was found in *Bonito 2,* because it included only few linear elements and big, compact oil palm plantations dominated the agricultural area. The rural section *La Gamba* also included many rectangular plantations, but also many linear elements, leading to a rather high index value of 1.29.

Similarity index (SIMI): The forest sections were characterized by very high values compared to the rural sections, ranging from 155.08 to 339.07 units, indicating that the vicinity of an average pixel was usually of similar patch type. The values of rural sections ranged only from 5.68 to 22.42 units and were lowest for the rural sections *Bonito 1*, *Bonito 2* and *La Gamba,* indicating that there patches were often adjacent to patches of very different type.

Contagion index (CONTAG): Rural sections showed intermediate indices with values ranging from 57.24% to 63.39%. The single rural sections could not be distinguished with this metric. Forest sections had higher indices ranging from 70.28% to 78.71% which refers to a high degree of patch type aggregation. These areas mainly included few and big forest patches and only few and small patches of other patch types (e.g. agriculture, pasture, fern-dominated vegetation etc.), which were typically situated near to adjacent rural areas.

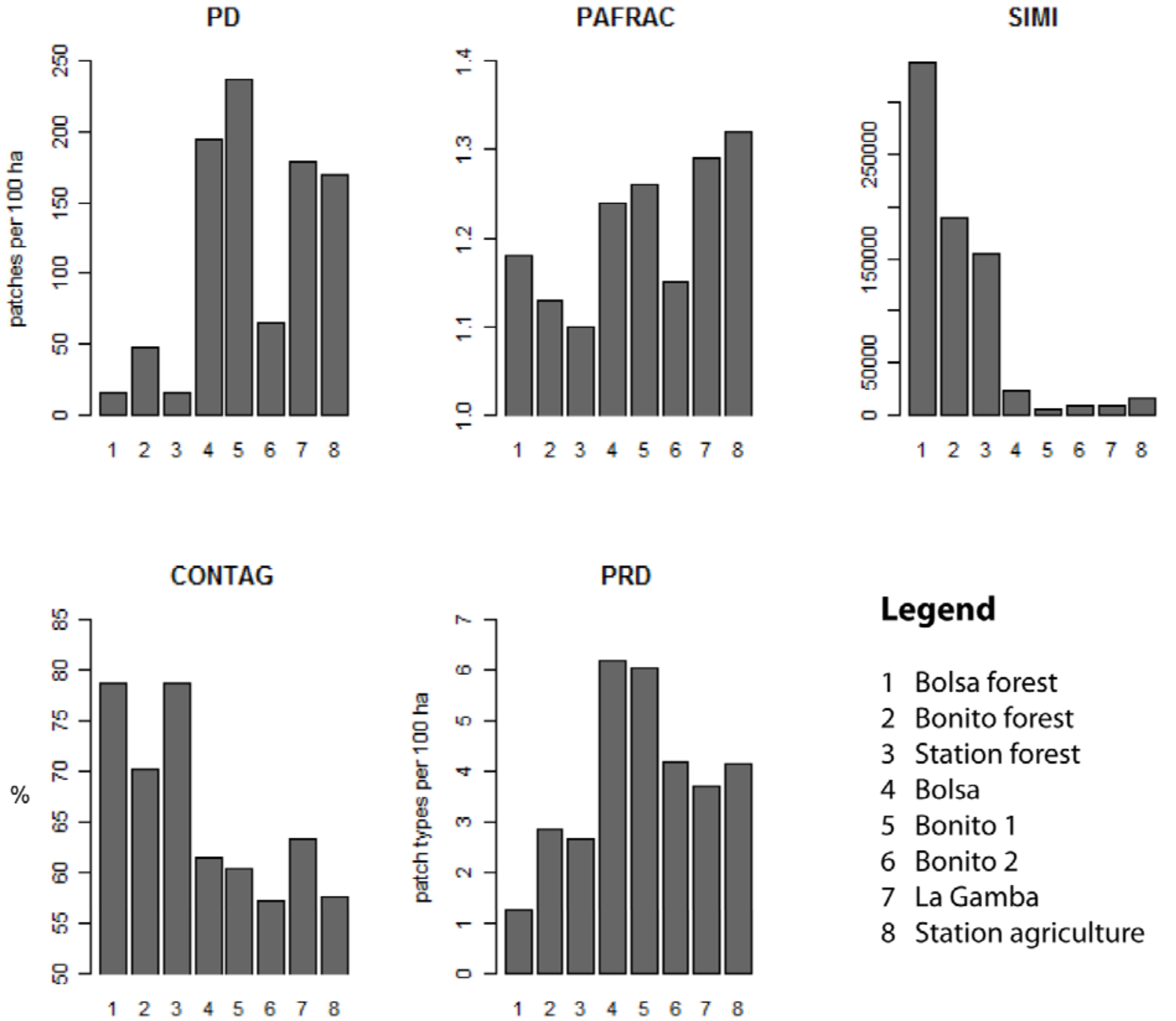

Figure 7: Values of the landscape level metrics. The values of the distribution statistic SIMI are the area-weighted means of the values of all single patches of the certain section.

Patch richness density (PRD): Forest sections were mainly dominated by few patch types (primary and secondary forest) and showed rather low PRD values ranging from 1.24 to 2.85. On the other hand, rural areas consisted of many different patch types and had relatively high values ranging from 3.71 to 6.18. The two smallest rural sections *Bolsa* and *Bonito 1* included ten of the eleven different land cover types and had the highest values of PRD. The rural sections *Bonito 2*, *La Gamba* and *Station agriculture* included all land cover types, but showed lower values of PRD due to their bigger size.

b. Characterization of patch types (class level)

Mean patch area (AREA): The categories primary and secondary forest had the biggest mean patch areas with 51.33 ha and 13.10 ha respectively. With 4.02 ha oil palm plantations had the biggest mean patch area of all agricultural patch types showing that plantations are usually of great extent. Pastures were characterized by a smaller mean patch area of 2.52 ha although in total they covered larger areas than oil palm plantations. All other land use types had mean patch areas smaller than 1 ha (Fig. 8).

<u>Fractal dimension (PAFRAC):</u> The lowest fractal dimensions were found in the categories primary forest, agriculture and secondary forests with values of 1.11, 1.13 and 1.15 in that order, which means that these land cover types were compactly shaped. Interestingly, oil palm plantations and pastures had very similar fractal dimensions of 1.17 and 1.19 respectively, demonstrating that pastures were not more complexly shaped than oil palm plantations. The category “drainage ditch and river” was characterized by a exceptionally high fractal dimension of 1.66 because it mainly consisted of very elongated patches. The same is valid for the categories “live fence and timber plantation” and “settlement and road” (Fig. 8).

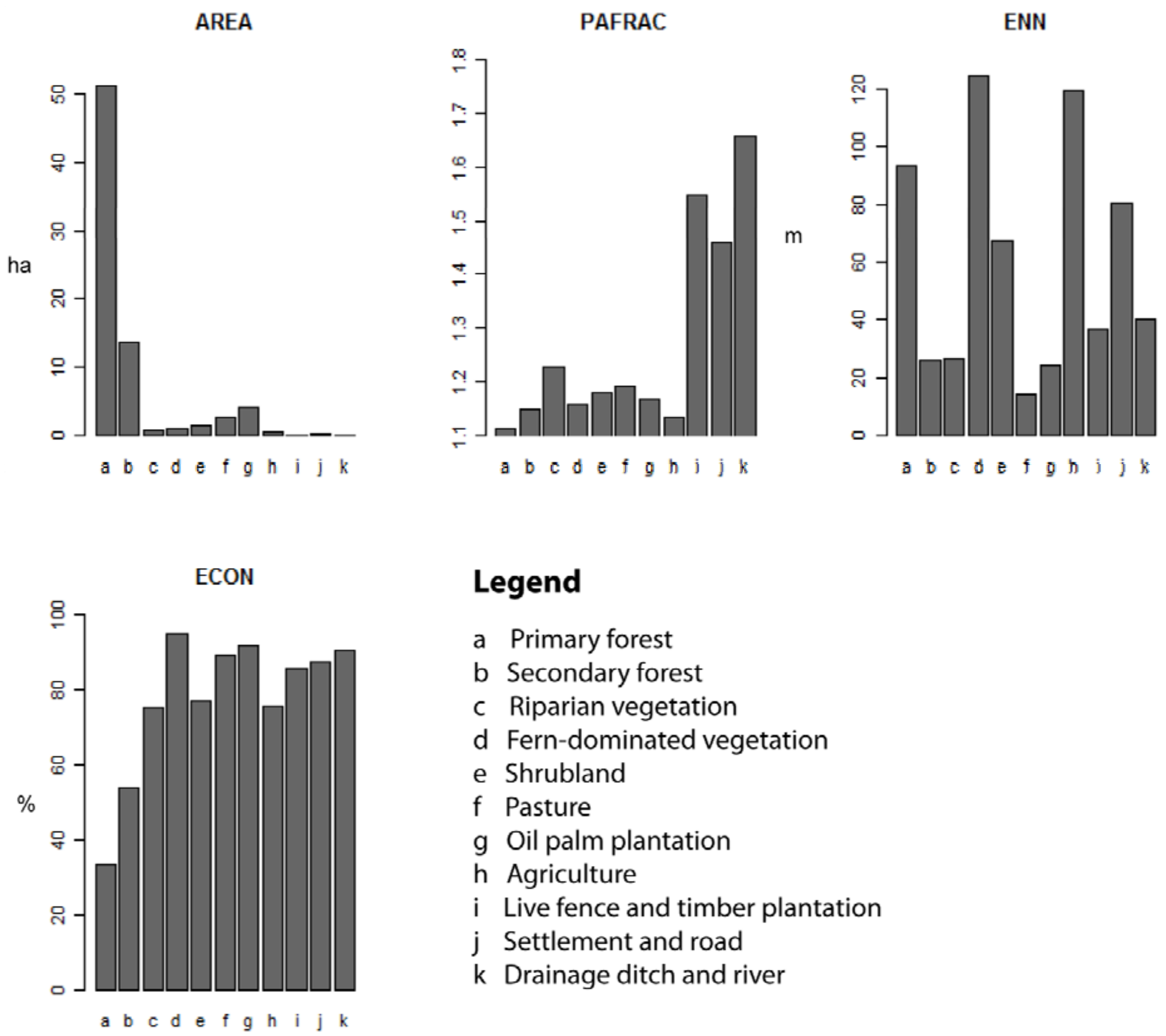

Figure 8: Values of the class level metrics. The values of the distribution statistics ENN and ECON are the area-weighted means of all single patches of the certain land cover type.

Euclidean nearest neighbor distance (ENN): The index values were lowest for the categories pasture and oil palm plantation with 13.82 m and 24.26 m respectively, indicating that patches of these types were generally close to each other. Fern-dominated vegetation had the highest value with 124.60 m indicating a high degree of isolation of this patch type. The categories agriculture and “settlement and road” were also characterized by high values of 119.43 m and 80.06 m caused by many small and disaggregated patches (e.g. single farms and houses). Primary forest and shrubland also showed considerably high values of ENN, while secondary forest and riparian vegetation had relatively low values.

Edge contrast index (ECON): The category primary forest showed the lowest ENN with a value of 33.51% referring to a high similarity of adjacent patch types. The value of secondary forest was about average with 53.98%. Interestingly, all other patch types were characterized by high edge contrasts with values higher than 75%. The highest edge contrast was found for the category fern-dominated vegetation with a value of 94.91%. Also the categories oil palm plantation, “drainage ditch and river” and pasture showed very high edge contrasts. Anthropogenic patch types generally showed higher ECON values than the natural patch types which means that they were often surrounded by patches of very different type.

c. Configuration of patch types - patch area vs. patch density

In the following the mean patch area and patch density of patch types were compared (Fig. 9). The category primary forest had the biggest mean patch area of 51.33 ha, but a very low patch density of only 0.51 patches per 100 ha. In comparison, secondary forests were characterized by a much lower mean patch area and a clearly higher patch density of 2.46 patches per 100 ha because most of these forests were abandoned farmland. Riparian vegetation covered only smaller areas, but showed a relatively high patch density of 4.91 patches per 100 ha because many small patches and strips of remnant riparian forests were present along the riversides.

Interestingly, oil palm plantations had nearly the same patch density as secondary forests with 2.53 patches per 100 ha. Pastures showed a smaller mean patch area than the plantations, but a significantly higher patch density of 6.51 patches per 100 ha which implies that pastures were usually smaller and more numerous. This reflects the fact that oil palm plantations are labor-intensive permanent cultures that probably are only profitable as extensive cultivations. Moreover, farmers expect greater profits from the oil palm production than from other cultivation types. The category agriculture was characterized by a small mean patch area and a small patch density as only few patches of this type were found. On the other hand, the category “settlement and road” had an exceptionally high patch density of 10.83 patches per

100 ha which results from the many single farms and houses outside the village. The category "live fence and timber plantation" also had a very high patch density of 16.13 patches per 100 ha in contrast to a very small mean patch area, probably because it included mainly live fences and roadside tree lines and only a few patches of timber plantations. The highest patch density was found in the category "drainage ditch and river" with 27.82 patches per 100 ha because drainage ditches and rivulets were very frequent linear landscape element types.

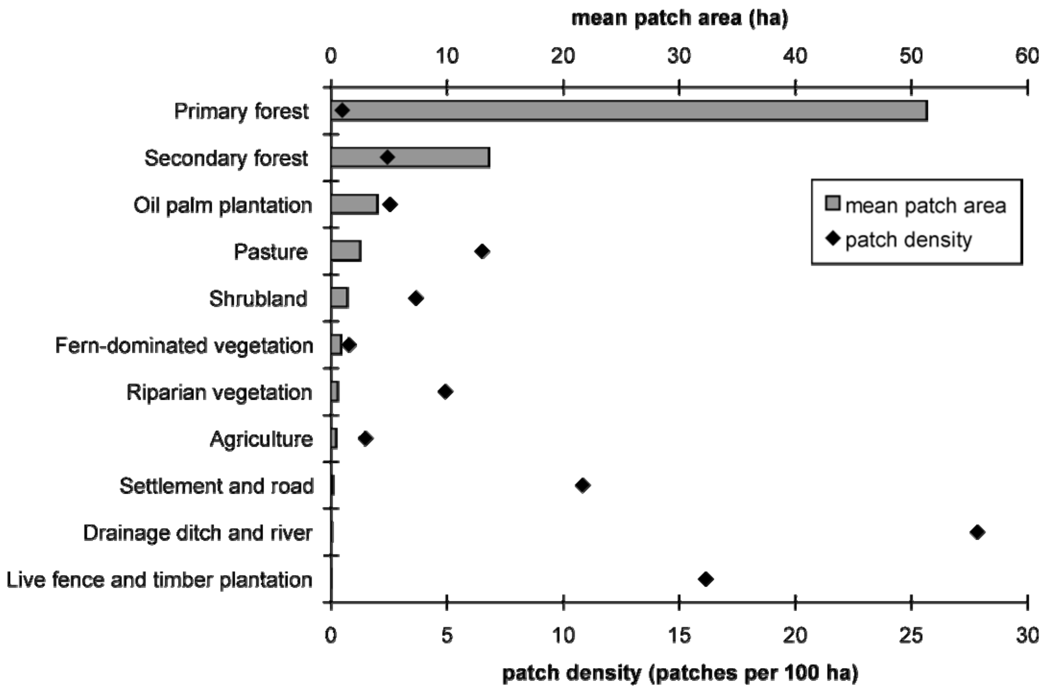

Figure 9: Mean patch area of the land cover types compared to their patch density.

5.2. Line elements

5.2.1. Structural parameters

In total 179 line elements were recorded and classified into cutting and connecting elements and analyzed regarding their structural parameters (length, height, width and fringe width). Cutting elements comprised 69 units and had a total length of 65.09 km which was 70.25% of the total length of all lines (Tab. 11 and Fig. 10). In comparison, connecting elements were more numerous with 110 units, but had a total length of only 25.56 km which was 29.75% of the total length of all lines.

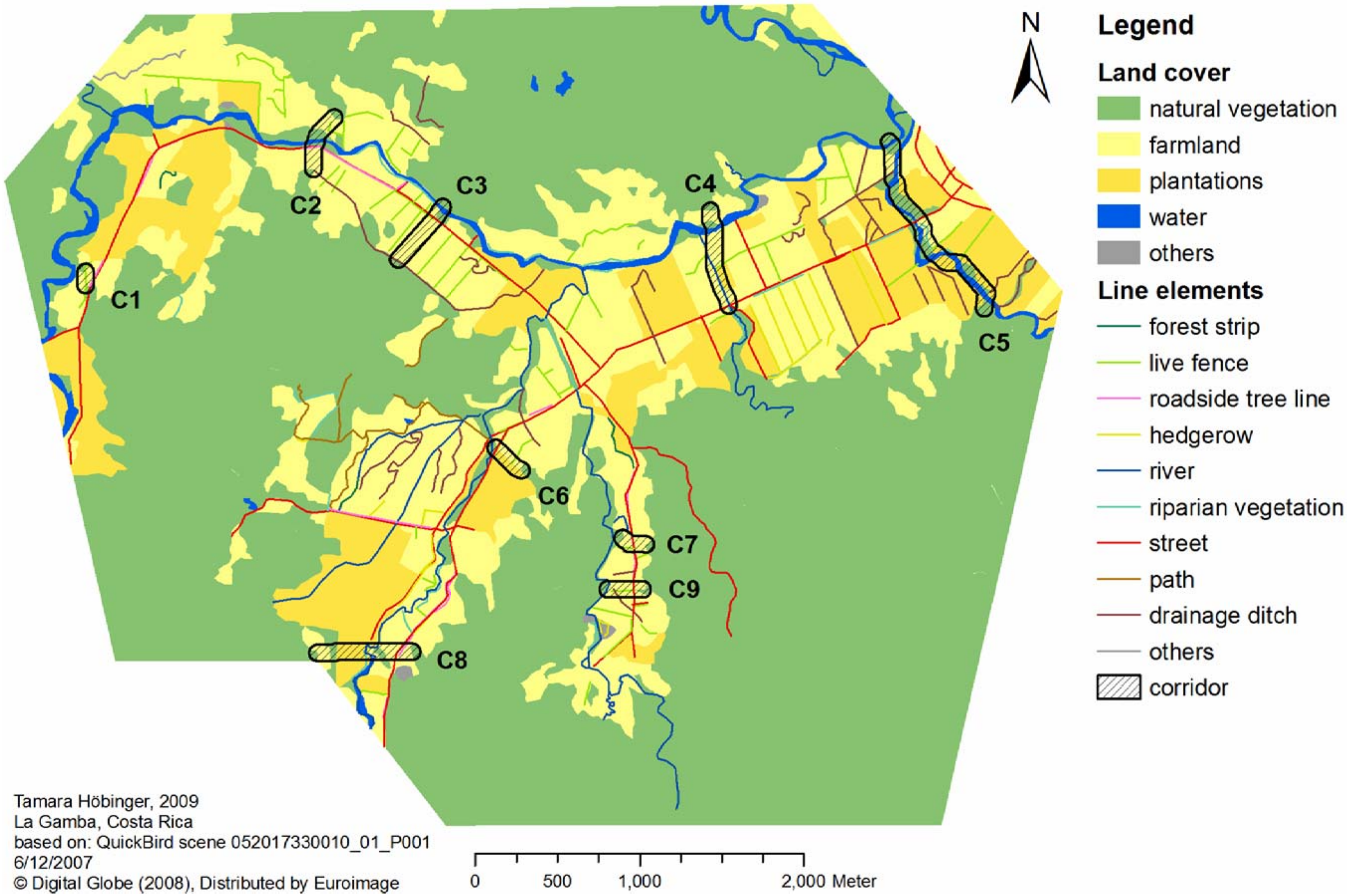

Figure 10: Spatial arrangement of line elements and computed corridor routes (C1 – C9) within the study area.

a. Mean length

An interesting fact is, that connecting line elements had a much shorter mean length (250.55 m) than cutting line elements (943.31 m) (Tab. 12). Especially the most natural types riparian vegetation and forest strips had very short mean lengths of 242.14 ± 28.93 m and 261.67 ± 59.80 m respectively and made up only a small proportion of the total length of all line elements (Tab. 11 and 12). Only few lines of forest strips were found because forest remnants are usually compact patches. On the other hand, roadside tree lines had the longest mean length of all connecting line elements with 351.08 ± 65.66 m. In contrast, live fences had the shortest mean length with 217.23 ± 18.22 m, but were the most numerous category including more than one third of all lines. Hedgerows had the second longest mean length of connecting line elements with 338.17 ± 59.52 m.

Table 11: Total lengths (m and %) of the line element types.

Type of line element	Total length [m]	Total length [%]
CONNECTING ELEMENTS	**27,560.59**	**29.75**
Live fence	13,177.23	14.22
Riparian vegetation	5,325.95	5.75
Roadside tree line	4,212.35	4.55
Hedgerow	4,059.71	4.38
Forest strip	785.35	0.85
CUTTING ELEMENTS	**65,088.26**	**70.25**
Street	22,084.08	23.84
Path	3,540.43	3.82
River	22,652.21	24.45
Rivulet	4,693.40	5.07
Drainage ditch	11,437.11	12.34
Others	681.03	0.74
TOTAL	**92,648.85**	**100**

Regarding cutting elements, streets had the longest and most variable mean length with 1003.82 ± 321.42 m. The high mean and standard error result from the long and continuous streets and short branching of roads. Footpaths, which were less frequent than streets, had a mean length of 505.86 ± 82.38 m. Altogether, streets and paths had a total length of 25.62 km which was more than a quarter (27.66%) of the total length of all line elements. They formed a highly connected system of lines within the study area (Fig. 10). Rivers and rivulets had total lengths of 22.65 km and 4.69 km respectively. Together they covered nearly one third (29.52%) of the total length of all line elements. Drainage ditches, which were fairly numerous, had a relatively long mean length of 381.2 ± 66.36 m.

b. Mean width, height and fringe width

The structural parameters width, height and fringe width also pointed out interesting differences between line element types (Tab. 12). Live fences and roadside tree lines had a very similar structure because both types were typically straight tree lines dominated by one or few tree species. They were characterized by a narrow mean width of 3.66 ± 0.46 m and 3.88 ± 0.74 m respectively. The mean heights of 9.75 ± 0.50 m of live fences and 9.17 ± 0.95 m of roadside tree lines were remarkably tall. Naturally, the broadest and tallest line elements were forest strips and riparian vegetation with mean widths of 15.00 ± 4.04 m and 8.50 ± 0.68 m and mean heights of 15.00 ± 0.58 m and 11.09 ± 0.80 m in that order. In contrast, hedgerows were the narrowest and lowest connecting line elements with a mean width of only 2.54 ± 0.36 m and a mean height of 4.25 ± 0.48 m.

Introduced (planted) line element types (live fences, roadside tree lines and hedgerows) had very narrow fringe widths of lesser than 1 m (see Tab. 12). In contrast, riparian vegetation and forests strips possessed clearly broader mean fringe widths of 1.83 ± 0.40 m and 1.50 ± 0.41 m respectively.

Table 12: Structural characteristics of line element types (mean and standard error).

Type of line element	Length [m]	Width [m]	Height [m]	Fringe width [m]
Live fence	217.23 ± 18.22	3.66 ± 0.46	9.75 ± 0.50	0.48 ± 0.08
Roadside tree line	351.08 ± 65.66	3.88 ± 0.74	9.17 ± 0.95	0.58 ± 0.10
Forest strip	261.67 ± 59.80	15.00 ± 4.04	15.00 ± 0.58	1.50 ± 0.41
Riparian vegetation	242.14 ± 28.93	8.50 ± 0.68	11.09 ± 0.80	1.89 ± 0.40
Hedgerow	338.17 ± 59.52	2.54 ± 0.36	4.25 ± 0.48	0.67 ± 0.11
Drainage ditch	381.20 ± 66.36	1.76 ± 0.12	--[3]	--
Street	1003.82 ± 321.42	3.09 ± 0.41	--	--
Path	505.86 ± 82.38	2.43 ± 0.20	--	--
River	--	4.50 ± 1.22	--	--
Rivulet	533.25 ± 133.63	2.25 ± 0.45	--	--

c. Structural parameters of live fences and roadside tree lines

In the following, live fences and roadside tree lines were summed up as live fences because of their similar characteristics. Together, live fences and roadside tree lines had a length of 17,340 m with a mean length of 239.54 m ± 19.40 m. Their mean width was 3.71 ± 0.40 m and the mean height 9.68 ± 0.44 m. Concerning the height of live fences, the measured values strongly depend on the date of record. The tall mean height indicates that the live fences have

[3] not available for this line element type

not been pollarded recently. The maximum height measured in a live fence was 18 m, which was remarkably tall and points out that live fences were not pollarded regularly. The widths of live fences usually corresponded to the crown width of the bigger trees as the fences typically did not show remarkable ground layers or fringe vegetation. Interestingly, the tree density was very high with a mean of 346.3 individuals per km. Probably the high tree density is necessary for attaching wires appropriately between the trunks. On the other hand, the density of live fences was relatively low. In view of the whole study area (25.66 km²) the density of live fences and roadside tree lines together was 6.76 m per ha, considering only the agricultural area (8.70 km²) it was 20.01 m per ha.

d. Adjacent land use and connectivity of live fences and roadside tree lines

An important aspect of live fences and roadside tree lines is the adjacent land use as it has strong influence on the grade of disturbance. Live fences mainly occurred as boundaries between pastures and along roads, but scarcely within or beside other land use types (Fig. 11). Remarkably, 69 out of 73 live fences bordered or divided pastures. 41 (55.41%) live fences were surrounded by pastures on both sides and 28 (37.84%) were bordered by pastures on one side. 14 (18.92%) fences were situated next to roads, eight (10.96%) beside rice or corn fields and five (6.85%) next to oil palm plantations. Only two live fences (2.74%) were surrounded by oil palm plantations on both sides. Other land use types as residential areas and rivers were scarcely adjacent to live fences.

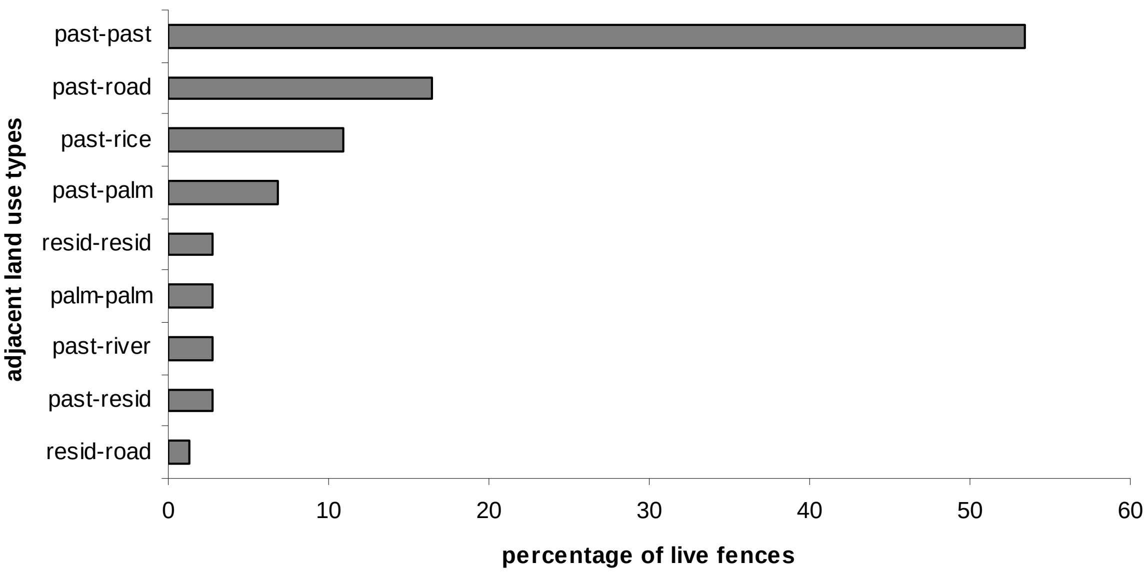

Figure 11: Land use types enclosing live fences. past = pasture, palm = oil palm plantation, resid = residential area, rice = rice and corn fields.

The connectivity to forests or other connecting line elements (Tab. 13) is an essential feature of live fences and roadside tree lines with respect to their function as wildlife corridors. Interestingly, nearly half of all live fences (46.57%) were linked to other connecting line elements. The mean length of these fences was rather short with 219.91 m. Only 13.70% of the fences were connected to forests, their mean length was shortest with 201.00 m. In contrast, isolated live fences (16.44%) had the longest mean length with 331.83 m.

Table 13: Connectivity of live fences and roadside tree lines to forests and other connecting line elements.

Connectivity	Percent	Mean length [m]
Linked to a connecting line element	46.57	219.91
Near to forest	20.55	226.47
Isolated	16.44	331.83
Linked to forest	13.70	201.00
Near to other connecting line element	2.74	291.00

Live fences positioned near to a forest (20.55%) were relatively short with a mean length of 226.47 m, while live fences positioned near to other connecting line elements (2.74%) were usually longer with a mean length of 291.00 m. In summary, live fences and roadside tree lines were linked to many connecting line elements, but the connectivity to forests was rather poor.

5.2.2. Ecological value

Based on the structural parameters all 110 connecting line elements were classified into three categories regarding their ecological value: category one (CAT 1) = low ecological value, category two (CAT 2) = average ecological value, category three (CAT 3) = high ecological value. The classification shall point out the state of connecting line elements, especially of live fences. The mean ecological value for all connecting line elements was 2.04. The ecological values of live fences and roadside tree lines were lowest with means of 1.87 and 1.92 respectively, while forest strips and riparian vegetation had the highest means with 3.00 and 2.45 in that order (Tab. 14).

CAT 2 was most important including 74.55% of all line elements. CAT 3 and CAT 1 comprised 14.54% and 10.91% respectively. The total length of lines belonging to CAT 2 was 21.22 km, the total length of lines of CAT 3 was 4.53 km and of CAT 1 it was 1.82 km. CAT 2, that was by far the largest group, comprised 77.05% of live fences, 91.67% of roadside tree lines, 54.55% of riparian vegetation and all hedgerows. CAT 3 included all three forest strips, as well as nearly half (45.45%) of the lines of riparian vegetation. Only three live fences and no roadside tree lines belonged to this category as these types were usually poorly structured and species poor. Remarkably, CAT 1 included only some lines of live fences and roadside tree lines, but no lines of the other line element types.

Table 14: Classification of connecting line elements according to their ecological value. % = percentage of line elements, km = total length.

Type of line element	Category 1		Category 2		Category 3		Total length	Mean ecol. value
	%	km	%	km	%	km	km	
Live fence	18.03	1.67	77.05	10.34	4.92	1.17	13.18	1.87
Roadside tree line	8.33	0.15	91.67	4.06	0.00	0.00	4.21	1.92
Forest strip	0.00	0.00	0.00	0.00	100.00	0.79	0.79	3.00
Riparian vegetation	0.00	0.00	54.55	2.75	45.45	2.57	5.32	2.45
Hedgerow	0.00	0.00	100.00	4.06	0.00	0.00	4.06	2.00
Total length [km]	--	1.82	--	21.21	--	4.53	27.56	--

5.2.3. Species compositions of live fences

At 54 sites (50 m long sections of live fences and roadside tree lines) all vascular plants with stem diameter >1 cm were recorded. In total 92 species were found, the mean number of species per site was 9.0. Regarding life forms the mean number of tree species per site was 4.5 and the mean number of treelet species 3.9. This illustrates that species richness at landscape scale was high, but that individual live fences usually included relatively few species. Frequencies showed clearly that only few species were very abundant, but many species occurred only at one or a few sites.

a. Planted species

In total only 21 (22.83%) species were definitely planted in live fences. These were mostly trees (19) as well as one treelet (*Dracaena fragrans*, Asparagaceae) and one liana (*Allamanda cathartica*, Apocynaceae). The most species rich families were Fabaceae (4 sp.), Lamiaceae (3 sp.) and Myrtaceae (3 sp.). *Erythrina fusca* (Fabaceae) was by far the most common species with a total of 576 individuals occurring at 79.63 % of the 54 investigation sites (Tab. 15, Fig. 12). *Gliricidia sepium* (Fabaceae) was the second most common tree with 99 individuals occuring at 31.48% of the sites followed by *Psidium guajava* (Myrtaceae) with 48 individuals at 29.36% of the sites. Only five species were found at more than 10% of the investigated sites while more than 50% had a frequency of less than 3.70%.

Table 15: List of vascular plant species planted in live fences.

Family	Scientific name	Life form	% of sites
Anacardiaceae	*Spondias mombin* L.	tree	5.56
Apocynaceae	*Allamanda cathartica* L.	liana	1.85
Asparagaceae	*Dracaena (fragrans)* (L.) Ker Gawl.	treelet	1.85
Bignoniaceae	*Crescentia cujete* L.	tree	5.56
Bixaceae	*Bixa orellana* L.	tree	3.7
Calophyllaceae	*Calophyllum brasiliense* Cambess.	tree	1.85
Chrysobalanaceae	*Licania platypus* (Hemsl.) Fritsch	tree	1.85
Combretaceae	*Terminalia amazonia* (J. F. Gmel.) Exell	tree	3.7
Euphorbiaceae	*Croton pictum* (L.) A. Juss	tree	1.85
Fabaceae	*Erythrina fusca* Lour.	tree	79.63
Fabaceae	*Gliricidia sepium* (Jacq.) Kunth ex Walp.	tree	31.48
Fabaceae	*Inga spectabilis* (Vahl) Willd.	tree	12.96
Fabaceae	*Zygia longifolia* (Humb. & Bonpl. ex Willd.) Britton & Rose	tree	3.7
Lamiaceae	*Tectona grandis* L. f.	tree	9.26
Lamiaceae	*Gmelina arborea* Roxb. Ex Sm.	tree	5.56
Lamiaceae	*Vitex cooperi* Standl.	tree	3.7
Malvaceae	*Theobroma cacao* L.	tree	1.85
Myrtaceae	*Psidium guajava* L.	tree	29.63
Myrtaceae	*Syzygium jambos* (L.) Alston	tree	9.26
Myrtaceae	*Syzygium malaccense* (L.) Merr. & L. M. Perry	tree	3.7
Rutaceae	*Citrus sinensis* (L.) Osbeck	tree	11.11

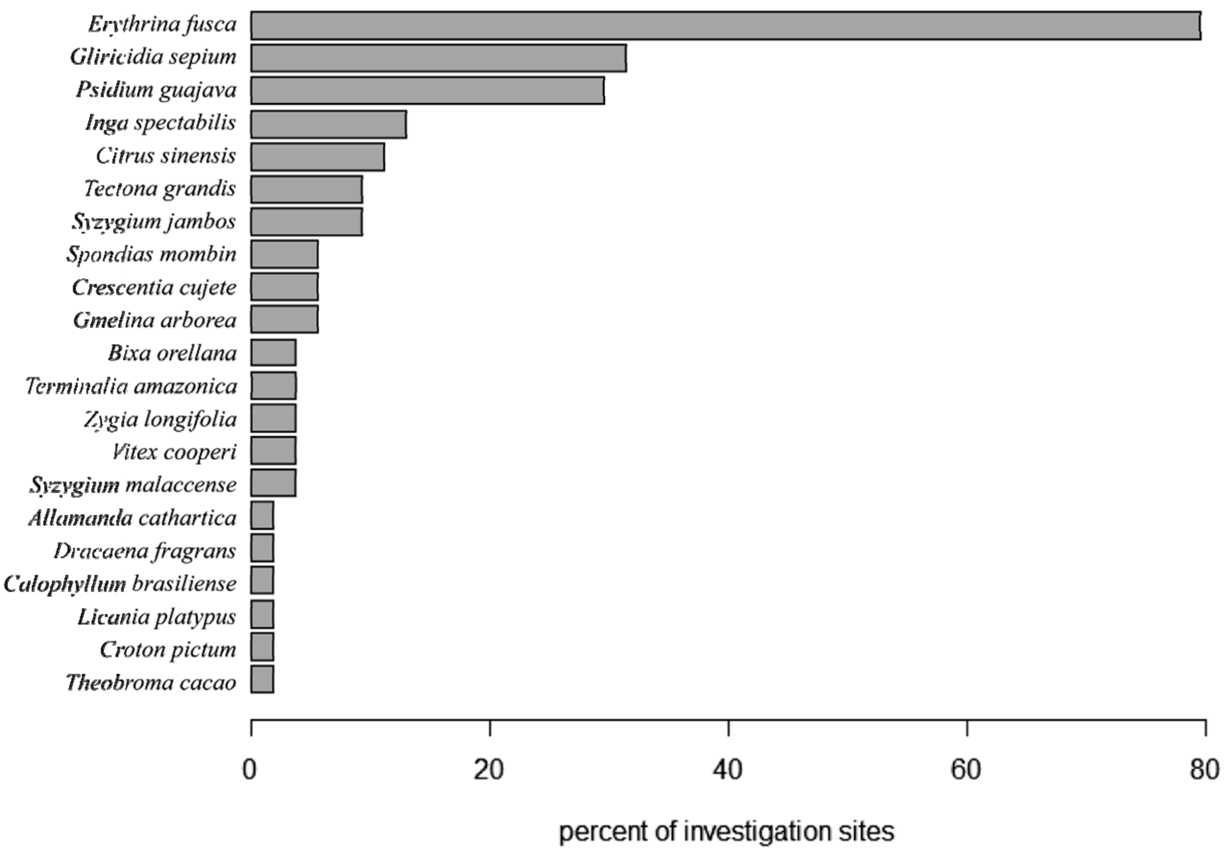

Fig. 12: Frequencies of species planted in live fences.

Several trees were planted as fruit source such as *Bixa orellana* (Bixaceae), *Syzygium jambos* (Myrtaceae), *Citrus sinensis* (Rutaceae) and *Theobroma cacao* (Malvaceae) or as timber trees such as *Tectona grandis* (Lamiaceae), *Gmelina arborea* (Lamiaceae) and *Terminalia amazonia* (Combretaceae). Species like *Erythrina fusca* (Fabaceae), *Psidium guajava* (Myrtaceae) or *Inga spectabilis* (Fabaceae) are very valuable for wildlife because they provide fruits and flowers. In particular, *Inga spectabilis* (Fabaceae) has a considerable ecological value as its fruits are an important food source for many different animal species.

b. Species that arose from natural regeneration

Most of the species (71) found in live fences were naturally grow (Tab. 16). Treelets and trees were the most common life forms (Fig. 13). The most species rich families were Melastomataceae (7 sp.), Moraceae (6 sp.), Asteraceae (4 sp.), Euphorbiaceae (4 sp.), Piperaceae (4 sp.) and Solanaceae (4 sp.).

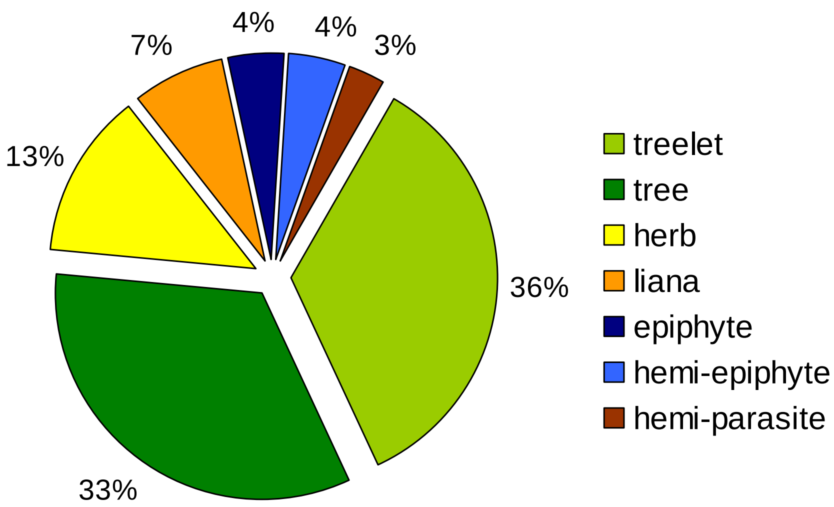

Figure 13: Proportions of life forms in live fences (naturally grown species).

The most common tree species arising from natural regeneration were *Miconia schlimii* (Melastomataceae), *Casearia arborea* (Salicaceae), *Miconia argentea* (Melastomataceae) and *Vismia baccifera* (Hypericaceae). The most common treelets (understorey plants) were species of the families Piperaceae (*Piper hispidum*, *Piper aduncum* and *Piper peltatum*) and Melastomataceae (*Conostegia subcrustulata* and *Clidemia crenulata*). Interestingly, only three species had a frequency of more than 50% and 14 had a frequency of more than 10% (Fig. 14), while more than 50% of the species had a frequency of less than 2%.

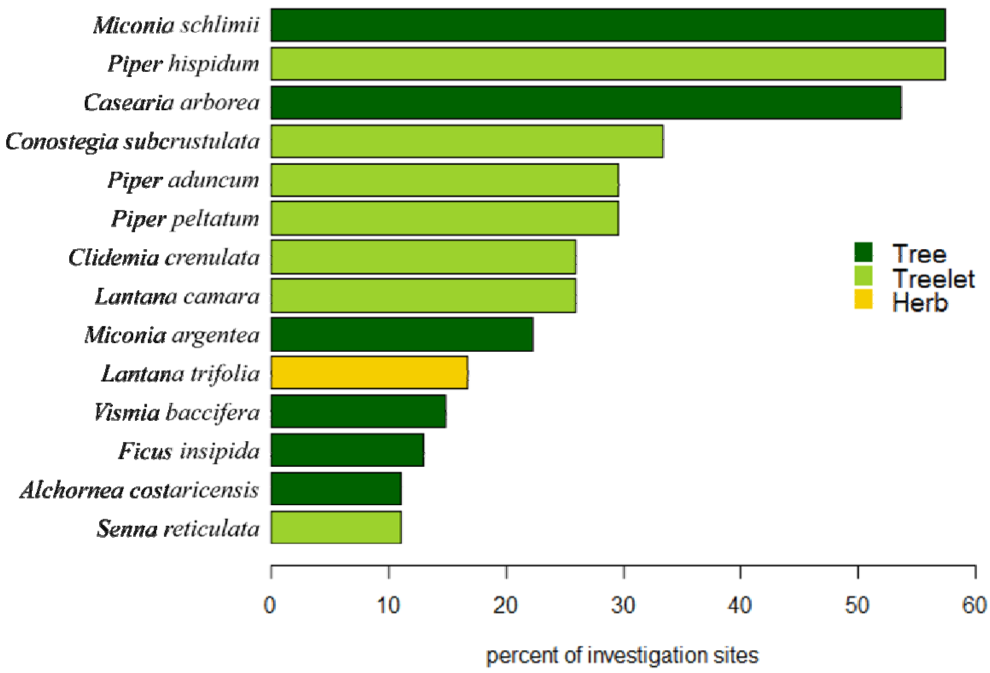

Figure 14: Frequencies of all naturally grown vascular plant species (stem diameter >1 cm) occurring at more than 10% of the investigation sites.

Table 16: List of vascular plant species in live fences that arose from natural regeneration.

Family	Scientific name	Life form	% of sites
Annonaceae	*Cymbopetalum costaricense* (Donn.Sm.) Salf.	tree	3.7
Annonaceae	*Guatteria amplifolia* Triana & Planch	tree	1.85
Annonaceae	*Guatteria chiriquiensis* R. E. Fr.	tree	1.85
Asteraceae	*Vernonia patens* Knuth.	treelet	9.26
Asteraceae	*Clibadium anceps* Greenm.	herb	1.85
Asteraceae	*Clibadium glomeratum* Greenm.	herb	1.85
Asteraceae	*Neurolaena lobata* (L.) R. Br.	herb	1.85
Boraginaceae	*Cordia spinescens* L.	vine/liana	3.7
Cyclanthaceae	*Carludovica drudei* Mast.	herb	1.85
Dilleniaceae	*Davilla kunthii* A.St. – Hil	shrub/liana	7.41
Dilleniaceae	*Doliocarpus hispidus* Standl. & L. O. Williams	shrub/liana	3.7
Dilleniaceae	*Doliocarpus multiflorus* Standl. & L. O. Williams	liana	1.85
Euphorbiaceae	*Alchornea costaricensis* Pax & Hoffm.	tree	11.11
Euphorbiaceae	*Cnidoscolus aconitifolius (Miller) I. M. Johnston*	treelet	1.85
Euphorbiaceae	*Croton schiedeanus* Schltdl.	treelet	1.85
Euphorbiaceae	*Sapium laurifolium* (Rich.) Griseb.	tree	1.85
Fabaceae	*Senna reticulate* (Willd.) H. S. Irwin & Barneby	treelet	11.11
Fabaceae	*Andira inermis* (W. Wright) Kunth	tree	1.85
Fabaceae	*Mimosa pigra* L.	treelet	1.85
Gesneriaceae	*Drymonia macrophylla* (Oerst.) H. E. Moore	epiphyte	1.85
Heliconiaceae	*Heliconia latispatha* Benth.	herb	5.56
Heliconiaceae	*Heliconia wagneriana* Petersen	herb	1.85
Hypericaceae	*Vismia baccifera* (L.) Triana & Planch	tree	14.81
Lacistemaceae	*Lozania pittieri* (S.F. Blake) L. B. Sm.	tree	1.85
Lauraceae	*Ocotea leucoxylon* (Sw.) Laness.	tree	1.85
Lauraceae	*Ocotea mollifolia* Mez & Pittier	tree	1.85

Table 16 (continued)

Family	Scientific name	Life form	% of sites
Lauraceae	*Ocotea sp.*	tree	1.85
Loranthaceae	*Struthanthus leptostachyus* (Kunth) G. Don	hemi-parasite	3.7
Loranthaceae	*Oryctanthus alveolotus* (Kunth) Kuijt	hemi-parasite	1.85
Malpighiaceae	*Hiraea fagifolia* (DC.) A. Juss.	liana	3.7
Malvaceae	*Sida martiana* A. St-Hill	herb	1.85
Marantaceae	*Calathea luthea* (Aubl.) Schult.	herb	3.7
Melastomataceae	*Miconia schlimii* Triana	tree	57.41
Melastomataceae	*Conostegia subcrustulata* (Beurl.) Wurdack	treelet	33.33
Melastomataceae	*Clidemia crenulata* Gleason	treelet	25.93
Melastomataceae	*Miconia argentea* (Schwartz) P.C.	tree	22.22
Melastomataceae	*Miconia trinervia* (Sw.) D. Don	treelet	7.41
Melastomataceae	*Miconia impetiolaris* (Sw.) D. Don	tree	5.56
Melastomataceae	*Clidemia capitelata* (Bonpl.) D. Don	treelet	1.85
Moraceae	*Ficus insipida* F.I. Willd.	tree	12.96
Moraceae	*Ficus maxima* Mill.	tree	7.41
Moraceae	*Ficus costaricana* (Liebm.) Miq.	hemi-epiphyte	3.7
Moraceae	*Ficus bullenii* I. M Johnst.	epiphyte	1.85
Moraceae	*Ficus colubrinae* Standl.	hemi-epiphyte	1.85
Moraceae	*Ficus citrifolia* Mill.	hemi-epiphyte	1.85
Myristicaceae	*Compsoneura sprucei* (A. DC.) Warb.	tree	9.26
Passifloraceae	*Passiflora quadrangularis* L.	vine	1.85
Phyllantaceae	*Hyeronima alchorneoides* Allemao	tree	1.85
Piperaceae	*Piper hispidum* Sw.	treelet	57.41
Piperaceae	*Piper aduncum* L.	treelet	29.63
Piperaceae	*Piper peltatum* L.	treelet	29.63
Piperaceae	*Piper auritum* Kunth	treelet	3.7
Polygonaceae	*Coccoloba obovata* Kunth	tree	1.85
Rubiaceae	*Hamelia patens* Jacq.	treelet	3.7
Rubiaceae	*Sabicea villosa* Roem. & Schult.	vine	3.7
Rubiaceae	*Palicourea guianensis* Aubl.	treelet	1.85
Rutaceae	*Amyris brenesii* Standl.	treelet	1.85
Salicaceae	*Casearia arborea* (Rich.) Urb.	tree	53.7
Sapindaceae	*Vouarana guianensis* Aubl.	tree	1.85
Simaroubaceae	*Quassia armara* L.	treelet	3.7
Solanaceae	*Solanum chrysotrichum* Schltdl.	treelet	3.7
Solanaceae	*Solanum antillarum* O. E. Schulz	treelet	1.85
Solanaceae	*Solanum sessiliflorum* Dunal	treelet	1.85
Solanaceae	*Witheringia mortonii* Hunz.	treelet	1.85
Theophrastaceae	*Clavija costaricana* Pittier	epiphyte	1.85
Urticaceae	*Cecropia peltata* L.	tree	9.26
Urticaceae	*Cecropia insignis* Liebm.	tree	5.56
Urticaceae	*Myriocarpa longipes* Liebm.	treelet	1.85
Verbenaceae	*Lantana camara* L.	treelet	25.93
Verbenaceae	*Lantana trifolia* L.	herb	16.67
Verbenaceae	*Citharexylum cf. viridi* Moldenke	treelet	1.85

Many of the naturally grown plants are dispersed by birds (e.g. *Psidium guajava*, Myrtaceae). This shows, that plant species of live fences are valuable as food source for animals and that birds play an essential role as seed dispersers.

5.2.4. Classification of live fences

a. Groups of live fences

Based on their plant species composition, live fences were classified by means of cluster analysis (K-means algorithm). Five groups could be defined: *Erythrina*-group (EG), *Erythrina*-dense-group (EDG), *Gliricidia*-group (GG), *Tectona*-group (TG) and Mixed-group (MG).

In the following the five groups of live fences were characterized by their most frequent plant species and structural parameters (Tab. 17). In 24 out of 54 investigated live fences *Erythrina fusca* (Fabaceae) was the dominant tree species. The groups differed in their main tree species which were planted by the farmers, showing that usually only one or two different tree species were used for establishing live fences. On the other hand, many of the naturally grown species were frequent in most live fences without significant tendency for any group, e.g. *Casearia arborea* (Salicaceae), *Clidemia crenulata* (Melastomataceae), *Conostegia subcrustulata* (Melastomataceae), *Lantana camara* (Verbenaceae), *Miconia schlimii* (Melastomataceae), *Piper hispidum* (Piperaceae) and *Piper peltatum* (Piperaceae).

Table 17: Species numbers and structural parameters of the different live fence groups.

	Species number			Length	Width	Height	Nr. of	Mn tree density
	mn	min	max	mn [m]	mn [m]	mn [m]	sites	[trees per 50 m]
***Erythrina*-group (EG)**	6.4	2	16	330.3	3.1	10.3	20	20.05
***Erythrina* dense-group (EDG)**	2.5	2	5	443.8	1.6	6.8	4	49.25
***Gliricidia*-group (GG)**	10.8	6	18	415.5	3.3	8.6	11	24.27
***Tectona*-group (TG)**	10.5	8	13	242.5	2.5	8.0	2	18.00
Mixed-group (MG)	9.5	4	19	272.2	4.8	9.9	17	18.82

1. *Erythrina*-group (EG)

EG was characterized by *Erythrina fusca* (Fabaceae), which was the dominant tree species of this group. Other planted tree species were rare. EG was the most important group comprising 20 of the 54 investigated sites (37.04%). The total species number ranged from two to 16. The mean species number of 6.4 species per site was relatively low compared to the other groups. The mean height (10.3 m) was the tallest of all groups, while the means of length (330.3 m), width (3.1 m) and tree density (20.05 trees per 50 m) were of average value. The naturally grown trees *Miconia schlimii* (Melastomataceae) and *Casearia arborea* (Salicaceae) were very frequent. Characteristic understorey species were the treelets *Clidemia crenulata* (Melastomataceae), *Piper hispidum* (Piperaceae) and *Piper aduncum* (Piperaceae).

2. Erythrina-dense-group (EDG)

In EDG *Erythrina fusca* (Fabaceae). The mean tree density was extremely high with 49.25 trees per 50 m (38 to 50 individuals of *Erythrina fusca* per site). EDG was a rare live fence type which was found only four times (7.41% of the investigation sites). The total species number ranged from two to five and the mean species number was the lowest of all groups with only 2.5 species per site. Interestingly, the mean length (443.8 m) was the longest of all groups, whereas the mean width (1.6 m) and mean height (6.8 m) were lowest, indicating that live fences of this group were poorly structured. The trees *Casearia arborea* (Salicaceae) and *Miconia schlimii* (Melastomataceae) were frequent, while other species were very rare. Only few understorey plants were found.

3. Gliricidia-group (GG)

GG was characterized by the tree species *Gliricidia sepium* (Fabaceae) which was frequent in this group, but scarcely present in the other groups. GG was found at eleven sites (20.37%). The total species number ranged from six to 18 and the mean species number of 10.8 was the highest of all groups. The mean values of length (415.5 m), width (3.3 m), height (8.6 m) and tree density (24.27 trees per 50 m) were also high compared to the other groups. Further common planted tree species were *Citrus sinensis* (Rutaceae) and *Erythrina fusca* (Fabaceae). Frequent, naturally grown trees were *Miconia schlimii* (Melastomataceae), *Casearia arborea* (Salicaceae) and *Vismia baccifera* (Hypericaceae). The most common treelets were *Conostegia subcrustulata* (Melastomataceae) and *Piper hispidum* (Piperaceae).

4. Tectona-group (TG)

In TG *Tectona grandis* (Lamiaceae) was the dominant tree species. This was the smallest group comprising only two of the investigation sites (3.70%). The total species number ranged from eight to 13, the mean species number of 10.5 was the second highest of all groups. On the other hand, the mean values of length (242.5 m), width (2.8 m) and height (8.0 m) of this group were relatively low. The mean tree density of 18 trees per 50 m was lowest of all groups. In one of the two live fences other tree species were rare, while the treelet *Conostegia subcrustulata* (Melastomataceae) occurred extremely numerous. Further, the treelets *Lantana camara* (Verbenaceae), *Piper hispidum* (Piperaceae) and *Clidemia crenulata* (Melastomataceae) as well as the liana *Cordia spinescens* (Boraginaceae) were frequent. This live fence delineated a teak plantation (also used as pasture) which most certainly was the reason why *Tectona grandis* was used to set up the fence. In the second live fence more tree species like *Erythrina fusca* (Fabaceae), *Psidium guajava* (Myrtaceae) and

Gliricida sepium (Fabaceae) were planted. *Casearia arborea* (Salicaceae) was also found, but probably resulted from natural regeneration. On the other hand, understorey plants were extremely rare in this live fence. Hence, the two fences of TG differed greatly in their species compositions and structure.

5. Mixed-group (MG)

MG included live fences that were not dominated by specific species. 17 of the 54 investigated sites (31.48%) were assigned to this group. The total species number ranged from four to 19 with a mean of 9.5. The mean length (272.2 m) was short compared to the other groups, while the mean width (4.8 m) and mean height (9.9 m) showed remarkably high values. The mean tree density (18.82 trees per 50 m) was very low. *Casearia arborea* (Salicaceae) and *Psidium guajava* (Myrtaceae) were the most frequent tree species, but were not found in all live fences of this group. The trees *Erythrina fusca* (Fabaceae) and *Miconia schlimii* (Melastomataceae) were also common. Characteristic understorey species were *Conostegia subcrustulata* (Melastomataceae), *Lantana camara* (Verbenaceae) and *Piper hispidum* (Piperaceae), all of them species that were also frequent in the other groups. Interestingly, MG was the only group including live fences with species of Heliconiaceae (*Heliconia latispatha* and *Heliconia wagneriana*). Some single sites of MG stroked out because certain, relatively rare species such as *Theobroma cacao* (Malvaceae), *Senna reticulata* (Fabaceae), *Inga spectabilis* (Fabaceae), *Drymonia macrophylla* (Gesneriaceae), *Bixa orellana* (Bixaceae) or *Cecropia peltata* (Urticaceae) occurred in great numbers. As no group specific species could be figured out and the live fences showed very different structural characteristics, MG represented a very heterogeneous assembly of live fences.

b. Associations between species number, position and group affiliation of live fences

The relation of the group affiliation to species richness of live fences was highly significant (Kruskal-Wallis ANOVA, Fig. 15a). Multiple comparison of the groups showed that group MG differed significantly from EG and EDG (*Erythrina*-dominated live fences) and GG differed significantly from EDG, but not from EG. ED and EDG as well as GG and MG did not differ significantly.

The association between positions and species richness was also evident (Wilcoxon Rank Sum Test, Fig. 15b). More than 50% of the investigated live fences were found beside roads (roadside) while the others were surrounded by pastures or other land use types (farmland). The mean species number of live fences beside roads (9.40) was significantly higher than the mean species number of live fences surrounded by farmland (7.08).

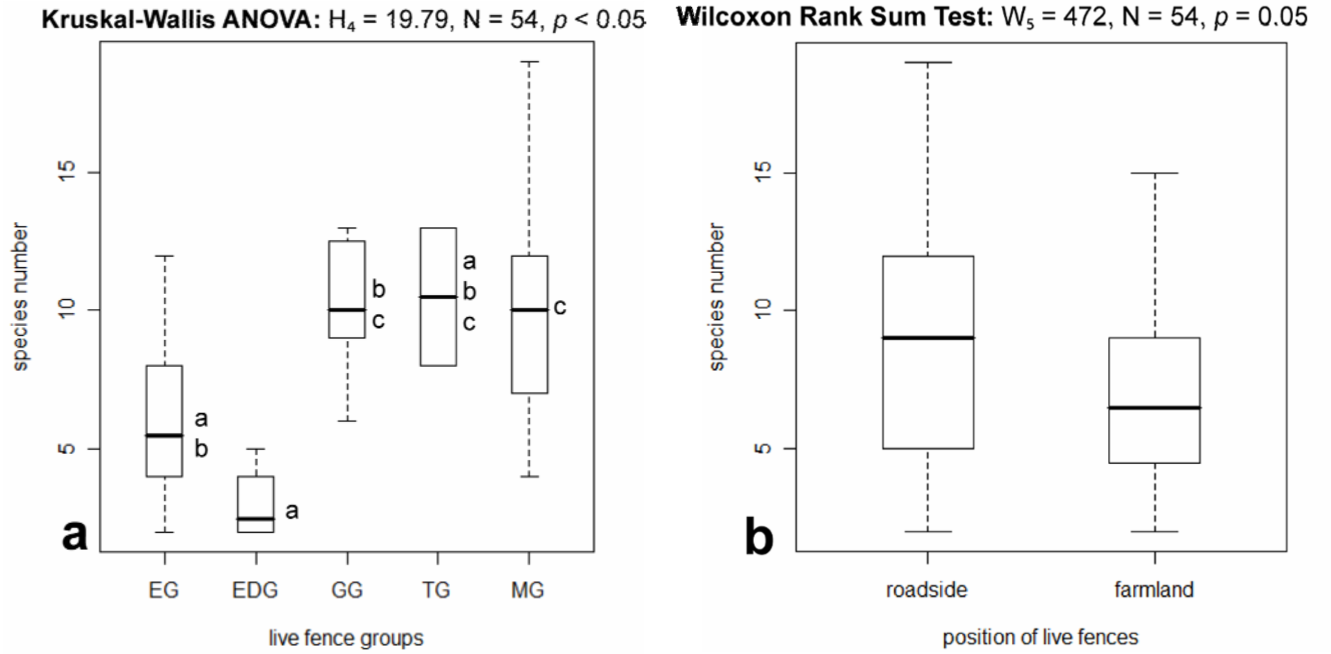

Figure 15: Relation of mean species number to a) group affiliation and b) position of live fences. Different letters in a) indicate significant differences between the groups. Boxplots: horizontal line = median, box = quantiles, whisker = 1.5 times interquantile range.

Group affiliation and position of live fences were not clearly associated (Fig. 16). Only live fences of GG were evidently more frequent within pastureland than along roads.

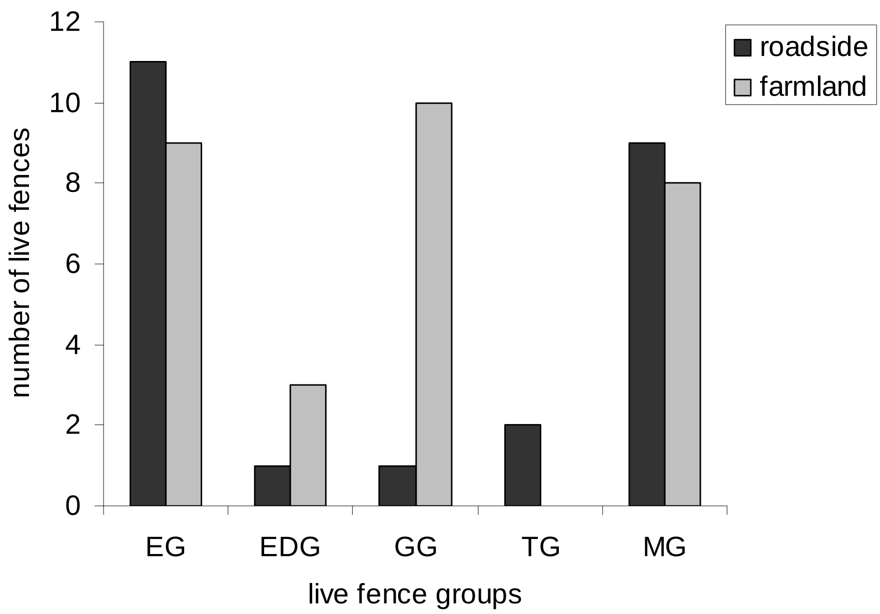

Figure 16: Relationship between position and group affiliation of live fences.

5.3. Computed corridor routes

In total nine least cost paths were found that connected the big forest patches of the study area crossing the agricultural area of La Gamba in parts where barriers and disturbances were minimal. The corridors C1, C2 and C3 traversed the Valle Bonito, C4 and C5 the section between La Gamba and the Interamericana, C7 and C9 the Valle Bolsa and C6 and C8 the agricultural area near the Tropical Station (Fig. 10 and 17). The lengths of the corridors (distances between the forest areas across farmland) ranged from 80 m to 1,295 m and the mean resistance values varied between 5.72 and 7.41 (Tab. 18).

Table 18: Lengths, resistance values and coordinates[4] of the start and endpoints of the corridor routes.

		Mean resistance	Start		End	
Corridor	**Length [m]**	**value**	**X [m]**	**Y [m]**	**X [m]**	**Y [m]**
C1	80	6.43	256,536	963,982	256,537	963,803
C2	360	5.72	258,078	964,902	257,920	964,507
C3	417	7.14	258,731	964,364	258,404	963,967
C4	598	7.33	260,328	964,351	260,457	963,683
C5	1,295	6.78	261,395	964,764	261,997	963,659
C6	209	7.41	258,989	962,901	259,221	962,701
C7	155	6.74	259,759	962,350	259,984	962,274
C8	576	6.69	257,890	961,616	258,563	961,622
C9	214	6.84	259,653	962,005	259,966	962,004

Corridor one (C1) linked the forest areas surrounding the most remote corner of the Valle Bonito. It was the shortest route passing only 80 m of pastureland. The mean resistance value of 6.43 was below average. C1 led through the narrowest part of the valley and included one live fence which was connected to both forest edges. The Valle Bonito is narrow in most of its parts, but extensive oil palm plantations, especially in this zone, leave only small parts of the valley without great hindrances for plant and animal movement. The road through the valley (width 5 m) was relatively quite compared to other roads in the area and was accompanied by roadside tree lines.

Corridor two (C2) connected the forest areas surrounding the center of the Valle Bonito and had a length of 360 m. The route passed only arboreal and abandoned pastures which was reflected by a mean resistance value of 5.72 which was the lowest of all corridors. In this part of the valley less oil palm plantations were present, but the frequently used road (width 5 m)

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[4] WGS 1984, UTM Zone 17N, False easting: 500,000, False northing: 0, Central meridian: -81, Scale factor: 0.9996

and the river Río Bonito (width 15 to 20 m) were considerable barriers for many organisms. C2 led through a narrow part of the valley where broad strips of riparian vegetation along both riversides were present. Along the road roadside tree lines were present and one live fence accompanied C2 for a short distance of 50 m.

Corridor three (C3) led across the Valley Bonito in the zone near to the village and passed 419 m of pastureland. The mean resistance value of 7.14 was above average because the corridor crossed a pasture with isolated trees and bordered settlement. In this part of the valley pastures dominated the agricultural area and the distance between the forest areas was relatively long. The Río Bonito was bordered by cultivated areas and forest. C3 crossed the river where a small forest patch was present at the cultivated riverside. The road leading through the valley (width 5 m) was very frequently used causing a great hindrance for many organisms. Live fences were present in the neighboring pastures, but not within the zone of the corridor.

Corridor four (C4) crossed the cultivated area between the village and the Interamericana leading from a riparian forest east of La Gamba to the forest north of the village. C4 was very long with a length of 598 m and had a considerably high mean resistance value of 7.33 because in this part of the landscape oil palm plantations and pastures without trees were the main cultivation types. The route followed the river Quebrada Chorro along most of its length, but neither riparian forests nor live fences were located within the corridor. Additionally, the street between La Gamba and the Interamericana (width 5 m) was very frequently used and not accompanied by roadside tree lines. In this area the Río Bonito usually bordered pastures or oil palm plantations at both riversides, but within C4 small patches of pioneer riparian forest were present.

Corridor five (C5) connected the forest areas near to the Interamericana and was the longest route with a length of 1,295 m. In this landscape part the distance between the forest edges was very great and oil palm plantations dominated the agricultural area. C5 followed the river Río Oro, passing several patches of riparian vegetation and forest. Nevertheless, the mean resistance value of 6.78 was about average because the route crossed the Río Oro four times (highest resistance value) and led through an oil palm plantation. The corridor also traversed the Río Bonito and the street between the village and the Interamericana (width 5 m) of which both were surrounded by riparian vegetation within the corridor zone.

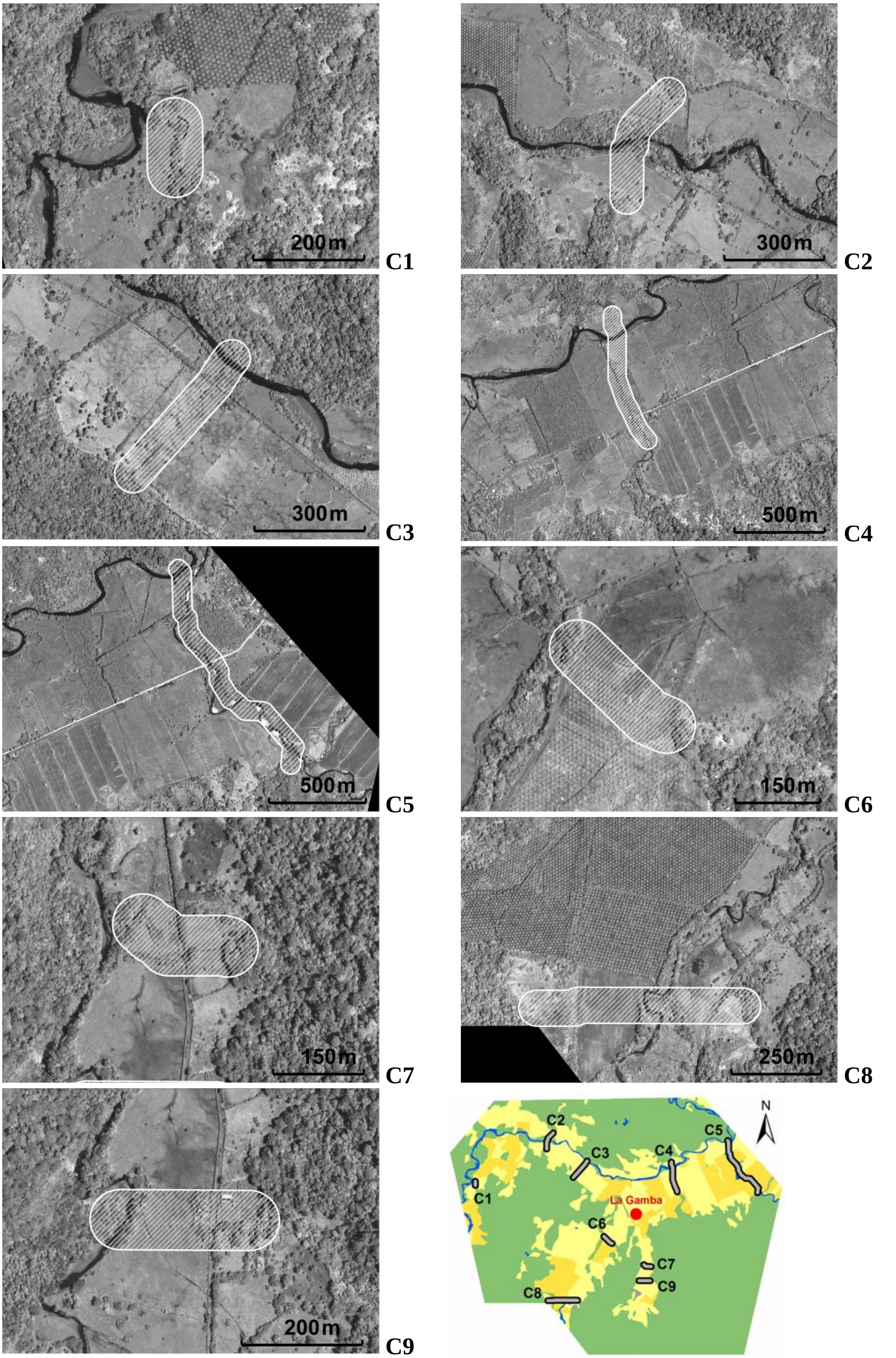

Figure 17: Illustration of the computed corridor routes (corridor width = 100 m) in detail (C1 – C9) and in the general map.

Corridor six (C6) passed the cultivated area southwest of the village and traversed 209 m of farmland. The mean resistance value was the highest of all corridors with 7.41 because the corridor bordered an oil palm plantation and settlement and traversed a rice field and a pasture without trees. In this part of the study area the distance between the forest areas was very great, but riparian forest along the Quebrada Gamba (total width around 50 m) extended from the forest area in the west of the study area into the farmland and a big part of the area was covered by abandoned pasture. The road crossed by C6 (width 4 m) was relatively quite. Live fences were not present along the route.

Corridor seven (C7) linked the forest areas surrounding the Valle Bolsa and was the second shortest route with only 155 m length. The mean resistance value of 6.74 was above average. The Valle Bolsa is very narrow and pastures dominated the agricultural area. Apart from the road and settlement, only few hindrances for wildlife movement were present. C7 led through the narrowest part of the valley and it included one short live fence (length 100 m). The road through the valley (width 2 m) was quiet and was accompanied by roadside tree lines. The corridor crossed the river Quebrada Gamba that bordered forest at one riverside and pastures or forest patches at the other. Within C7 at both riversides riparan forest was there.

Corridor eight (C8) connected the forest areas in the southwest of the study area and had a length of 756 m. Although the route led through an oil palm plantation, the mean resistance value of 6.69 was slightly below average because it also passed two forest patches and an abandoned pasture (low resistance values). In this area one very big oil palm plantation was present which left only small space for plant and animal movement between the forest areas. C8 traversed the river Quebrada Gamba, riparian vegetation was not present. Furthermore, the route crossed a frequently used road (width 4 m).

Corridor nine (C9) connected the forest areas surrounding the Valle Bolsa south of C7 where the valley becomes broader. Pastures were the main land use type in this area. The corridor had a length of 214 m and the mean resistance value of 6.84 was slightly above average. It passed a pasture with isolated trees and included one live fence (length 130 m) which was not linked to the forest edges. In addition, C9 crossed the road through the valley which was accompanied by roadside tree lines and it traversed the river Quebrada Bolsa (width 3 m) which bordered forest at one riverside.

6. DISCUSSION

6.1. Land use

6.1.1. Land cover and land use change

The loss and fragmentation of tropical forests and rapid changes in land use have great influence on the population dynamics of various native plant and animal species (TEWKSBURY ET AL. 2002, MORERA ET AL. 2005, ESCOBEDO-MORALES AND MANDUJANO 2007, HARVEY ET AL. 2008b, SINAC 2009). The land use in La Gamba has gone through continuous changes during the last decades due to different economic trends and developments. At the time of investigation still big forest areas were left in the study area. More than 60% of the investigated area were forested and more than 25% were covered with primary forest. One third of the area belonged to anthropogenic ecosystems of which pastures and oil palm plantations covered the biggest parts. Other crops were mainly cultivated for private use only, indicating that the agriculture in La Gamba strongly relied on regional trends and national policies.

The extremely warm and humid climate conditions demand much experience in farming methods for the successful cultivation of vegetables, timber and fruit trees. Many of the farmers have a lack of this knowledge because most of them come from families of former banana plantation workers and not from families with farming tradition (personal comment WEISSENHOFER 2009).

In order to reconstruct the agricultural development of the village La Gamba former land use maps (KLINGLER 2007) were compared. The deforestation rates were greatest during the 1950s when extensive banana plantations were established. Additionally, national policies forced cattle breeding which increased the deforestation process. In 1961 the banana industry in La Gamba collapsed (mainly due to mismanagement) which led to great changes in the economy and agriculture. In the following years most banana plantations were converted into pastures and rice fields. Big forest areas were cleared to gain more pastureland. In the 1970s the deforestation process slowed down, but still more areas were deforested and converted into farmland. During that time pastures and rice fields covered nearly the entire agricultural area. In the 1980s and 1990s a slight reduction of agricultural areas was noticeable. The land use did not change a lot, but became more diverse. Pastures and rice fields were still the major cultivation types, but the first oil palm plantations were established (after 1995). Some plantations of timber wood and small cultivations of cacao, banana and sugar cane were also present that time (KLINGLER 2007).

During the last decade the land use changed significantly because of the enormous increase in oil palm plantations on cost of pastureland and rice fields. The production of oil palms established relatively late in the village, but it increased very swift. In 2008 oil palm plantations were already the second most area consuming land use type and nearly half of the recorded plantations were younger than 3 years. Conversely, the extend of rice fields decreased sharply within a short time. In 2008 only few, small fields existed, apart from one relatively big field situated near the to village. Former rice fields were converted into oil palm plantations, pastures, or were not cultivated any more. On the other hand, in the Valle Bonito three pastures were prepared for rice cultivation just shortly after the investigations for this study were finished. This shows that the cultivation of many fields changes from time to time and that the proportions of land use types are not constant. Probably this variability of land use will decline, as more and more oil palm plantations, that are permanent cultures, determine the agricultural area of La Gamba.

As palm oil became more important on the world market during the last years (CORLEY AND TINKER 2003) there is to expect a further expansion of oil palm plantations in La Gamba. If new plantations are established, an important matter is where that will be done. The inclination map (Fig. 6) clearly demonstrates that nearly all plain areas (mostly river plains) were cultivated, whereas slopes steeper than 5° were mostly covered with forest. Hence, the steep, hardly accessible terrains were refuges for natural vegetation, while lowland rainforests and riparian forests on plain areas almost disappeared. Other studies on land use in tropical regions showed that pastures, temporal and permanent cultures are possible up to inclinations of 40° (MORERA ET AL. 2007). In this study parts of pastures and plantations were found at inclinations up to 37°, but only at the margins of the cultivated areas. Expansion of farmland, especially intensive crops like oil palms to steeper zones, involves certain risks such as loss of natural vegetation and soil degradation. For this reason, the steeper areas of the region should remain uncultivated and covered with forest.

Today the economic situation of farmers in La Gamba is poor. Due to a lack of knowledge of sustainable agriculture, mismanagement of land led to degradation of soils and abandonment of agricultural areas (MORERA ET AL. 2005). In order to improve the economic situation and the landscape structure, sustainable land use techniques and deliberate landscape planning are urgently needed. The Tropical Station La Gamba launched several interrelated social and ecological projects in cooperation with the farmers. The aim is to ensure the continued existence of the people living in La Gamba and to avoid ongoing deforestation. One of the intentions is to increase agrarian biodiversity through organic agriculture and permaculture in form of mixed cultures with fruit and wood trees and vegetables. This is an important contribution to preserve genetic resources and to protect the natural environment (personal comment HUBER 2009).

6.1.2. Landscape metrics

Landscape metrics are a useful tool to analyze landscape pattern, to compare different landscapes, and to monitor landscape change (UUEMAA ET AL. 2009). Many metrics are dimensionless and therefore only applicable for comparative analysis. Some consideration have to be taken into account when working with landscape metrics, as the wrong use of metrics can lead to false or confusing results. Several authors wrote about the use and misuse of landscape metrics (e.g. LI AND WU 2004) and tried to figure out appropriable sets of metrics for different scales and scientific questions (O'NEILL ET AL. 1988, 1996, TURNER ET AL. 1989, LI AND REYNOLDS 1993, MCGARIGAL AND MARKS 1995, BOTEQUILHA LEITÃO ET AL. 2006, CUSHMAN ET AL. 2008). Many of the existing metrics are partially or completely redundant because they represent similar information. For this reason, a careful choice of metrics is essential to avoid redundancies and misleading results (MCGARIGAL AND MARKS 1995, SCHINDLER ET AL. 2008, 2009).

For this study eight landscape metrics were chosen with regard to the suggestions of other authors (BOTEQUILHA LEITÃO ET AL. 2006, CUSHMAN ET AL. 2008, SCHINDLER ET AL. 2008). To detect differences among rural and forest sections the landscape metrics PD, PAFRAC, SIMI, CONTAG and PRD were calculated. These metrics clearly distinguished forest and rural sections. Fractal dimensions were considerable high for rural areas which can be caused by very high values of PAFRAC for the categories "settlement and road", "drainage ditch and river" and "live fence and timber plantation" which included many linear elements (Fig. 8). This clearly demonstrates the impact of linear elements on PAFRAC in this study. PRD clearly separated rural and forest sections, but varied among the rural areas of which all included at least ten of the eleven different land cover types. In comparison, the Simpson's Diversity Index, which also considers the landscape proportions occupied by the land cover types, showed similar values for all rural sections, but it could not separate them from the forest sections as clearly as PRD (HÖBINGER, unpublished data).

As linear landscape elements have a strong influence on the values of landscape metrics (LAUSCH AND MENZ 1999) several metrics used in this study behave differently compared to analysis focusing solely on areal landscape patches. For example, the results of this study are not consistent with other studies proposing that human activities such as agriculture cause simple and compact shaped landscape patches (O'NEILL ET AL. 1988). All rural sections had higher fractal dimensions than the forest sections with exception of section *Bonito 2*, which would mean that patches in rural areas were more complex shaped than those in forest areas. Actually, the landscape patches in rural areas were mostly simple shaped, but due to the inclusion of linear elements fractal dimensions were high, referring to a high density of line elements rather than only to a high complexity of landscape patches. Patch density is also strongly influenced by linear elements because the lines represent additional "patches" and increase the number of patches per area. The similarity index and the contagion index were not strongly influenced by the line elements.

The majority of studies on landscape metrics does not consider linear landscape elements (but see SCHINDLER ET AL. 2008). Linear elements are rarely visible on images with coarse grain size, which probably is one reason for their exclusion. Further, the influence of linear elements on the values of landscape metrics is not requested in analysis focusing exclusively on the configuration and characteristics of areal landscape patches.

The comparison of AREA and PD exemplified the configuration of the patch types. Interestingly, pastures had a lower AREA and a much higher PD than oil palm plantations, although they covered greater parts of the agricultural area. This demonstrates that oil palm plantations are mostly monocultures of great extend. The land use map (Fig. 10) shows that, conversely to pastures, oil palm plantations were never divided and scarcely bordered by live fences. Hence, the expansion of these plantations involves the risk of a simplifying of the landscape structure and the loss of small natural landscape elements in agricultural areas. This can lead to a significant reduction or a shifting of the biodiversity in anthropogenic ecosystems.

MORERA ET AL. (2007) who investigated the zone between the Piedras Blancas National Park and the Fila Costeña, obtained similar results for the relation of patch density to mean patch area with the difference that permanent cultures as palm plantations showed smaller mean patch areas compared to pastures. On the other hand, timber plantations were of relatively great extend compared to the other patch types. Further, patches of temporal cultures were more frequent in this region. MORERA ET AL. (2007) also analyzed the shapes of the land cover categories by means of fractal dimension, but due to a bigger size of the study area (117.8 km²), a different grain size of the land cover map and the exclusion of linear landscape elements, the values of PAFRAC were not comparable to the results of this study (e.g. O'NEILL 1988, 1996, TURNER ET AL. 1989, LI AND REYNOLDS 1993, MCGARIGAL AND MARKS 1995, BOTEQUILHA LEITÃO ET AL. 2006).

6.2. Line elements – live fences

6.2.1. Structural parameters

Live fences were the most important line element type in the study area including more than half of all connecting elements and more than one third of the total number of line elements. They were most common in pasture dominated areas as their main functions are the delineation of pastures and restriction of cattle movement.

This study showed that live fences were usually short, narrow and densely planted. Compared to the results of HARVEY ET AL. (2005) and CHACÓN LEÓN AND HARVEY (2007) live fences in La Gamba were relatively long and tall, whereas the mean widths were similar (Tab. 19). The high mean tree height of live fences (9.68 m) indicates that live fences in La Gamba are not pollarded that frequently than in other regions and that certain trees (especially timber trees) may not be pollarded at all (personal comment WEISSENHOFER 2009). In La Gamba the mean tree density was very high with 380 individuals per km. Contrary, the density of live fences was extremely low with only 20 m per ha, although pastures covered the biggest proportion of the agricultural area. The low density of live fences results from many undivided pastures of great extend (mean patch area 2.52 ha). Pastures were scarcely divided into smaller paddocks and rotational cattle grazing was not common in La Gamba. This involves the permanent disturbance of the entire grazing land due to the grazing activity and movement of the cattle which, in turn, allows only a small set of undemanding plant species to colonize pastures.

Because CHACÓN LEÓN AND HARVEY (2007) observed only live fences with a bending <15° and a density of >20 trees per 100 m, the values of tree density and density of live fences in this study are blurred and can not be compared to the results of the other studies (HARVEY ET AL. 2005, HÖBINGER 2010).

Table 19: Comparison of the structural characteristics of live fences in different study areas.

Investigated parameters	HARVEY ET AL. 2005	HARVEY ET AL. 2005	CHACÓN LEÓN AND HARVEY 2007	HÖBINGER 2010
Study area(s)	Cañas, Río Frío, Rivas and Matiguás	Río Frío	Río Frío	La Gamba
Mean length [m]	164.3	86.7	147.8	240.0
Mean width [m]	3.76	--[5]	--	3.71
Mean height [m]	7.40	6.77	--	9.68
Tree density [ind/km]	323.1	123.0	876.0	380.0
Density of live fences [m/ha farmland]	140.0	230.0	50.5	20.0

Regarding the position of live fences, this study ascertained that live fences were most common within or along pastures where they have several functions such as dividing pastures, providing shadow for the cattle and restricting cattle movement. Seldom they were used to delineate other properties. In La Gamba more than 50% of the live fences were surrounded by pastures on both sides and nearly 20% were positioned between pastures and roads. Only 6.85% of the fences were found between pastures and oil palm plantations, 10.89% between pastures and rice or corn fields and 9.26% beside residential areas. CHACÓN LEÓN AND HARVEY (2007) obtained very similar results with the difference that in the study area Río Frío no live fences were located beside rice or corn fields.

6.2.2. *Species compositions*

Although the species richness of live fences at landscape scale was considerably high compared to anthropogenic ecosystems with 92 recorded vascular plant species (stem diameter >1 cm), most individual live fences were species poor. In total 42 tree species were recorded, but the mean number of tree species per fence was only 4.52. Compared to other studies, the tree species diversity of live fences in La Gamba was moderate. HARVEY ET AL. (2005) found a total of 27 (Río Frío) to 85 (Cañas) tree species in live fences and the mean number of tree species ranged from 1.38 (Río Frío) to 7.48 (Rivas), whereas life fences were more diverse where more trees arose from natural regeneration. Most live fences in La Gamba were dominated by one or two tree species. In 24 out of 54 investigated sites *Erythrina fusca* (Fabaceae) was the dominant tree. Regarding life forms, trees and treelets were the most common life forms. Similar results have been obtained in previous studies (e.g. BUDOWSKI 1987, HARVEY ET AL. 2005).

[5] not specified

The species compositions of live fences strongly depends on ecological and physical conditions and the way live fences are established (e.g. grown from cuttings) and managed (staggered, partial or complete pollarding). Live fences of drier regions clearly differ from those in humid regions, especially regarding the dominant tree species (HARVEY ET AL. 2005).

The dominant tree species are usually those that are planted by the farmers. The most common planted tree in La Gamba was *Erythrina fusca* (Fabaceae). *Erythrina* species prefer humid climates and are generally very suitable for establishing live fences as they grow fast, quickly produce new branches and consequently endure pollarding very well. New trees can be grown from cut branches which makes the reproduction of the trees very easy. In the wild *Erythrina fusca* grows in freshwater swampy areas, but also in wet lowland forests and along rivers (GUTTERIGE AND SHELTON 1994, HARVEY ET AL. 2005, GARGIULLO 2008). The second most import tree was *Gliricidia sepium* (Fabaceae) that also easily produces roots from cuttings or stakes. It tolerates a wide range of climate conditions and it is a forage tree species capable of leaf yields. It grows wild in open areas of seasonally dry regions on the Pacific slope, but it is widely cultivated (GUTTERIGE AND SHELTON 1994, GARGIULLO 2008).

Other frequently planted trees were *Psidium guajava* (Myrtaceae), *Inga spectabilis* (Fabaceae) and *Citrus sinensis* (Rutaceae). Additionally, some farmers planted valuable fruit and timber trees in live fences. The planted tree species were generally well adapted to the climatic conditions, but many of them do not naturally grow in this region. Because many farmers in La Gamba come from the north of Costa Rica, they plant several species in live fences that are commonly used there (e.g. *Gliricidia sepium*). Nevertheless, only five of the planted trees were not native to Central America. These were *Tectona grandis* (Lamiaceae), *Gmelina arborea* (Lamiaceae) and *Syzygium jambos* (Myrtaceae) which originate from southeast Asia, *Syzygium malaccense* (Myrtaceae) that is native to Malaysia and Indonesia and *Citrus sinensis* (Rutaceae) which originates from southwest Asia (GARGIULLO 2008).

Common trees arising from natural regeneration, that are also suitable for live fences are *Casearia arborea* (Salicaceae), *Miconia argentea* (Melastomataceae), *Miconia schlimii* (Melastomataceae), *Vismia baccifera* (Hypericaceae) and *Ficus insipida* (Moraceae). These and other native tree species could be used to enrich live fences as they apparently endure pollarding well and are adapted to the environmental conditions in life fences. As many of them can not be grown from cuttings, their reproduction may be a bit difficult, but like for the reforestation project, seedlings could be grown in the plant nursery of the Tropical Station La Gamba to provide young plants for the farmers.

6.2.3. Classification

Five different groups of live fences could be distinguished using cluster analysis based on plant species compositions: *Erythrina*-group (EG), *Erythrina*-dense-group (EDG), *Gliricidia*-group (GG), *Tectona*-group (TG) and Mixed-group (MG). These can be classified into three main types: 1) *Erythrina*-dominated live fences (EG and EDG), 2) *Gliricidia*-dominated live fences (GG) and 3) live fences dominated by other species (TG and MG). The groups differed in their dominant tree species, while other trees and understorey species often did not show a clear tendency for a certain group.

Two groups, EG (*Erythrina*-group) and EDG (*Erythrina*-dense-group), were identified by the dominance of *Erythrina fusca* (Fabaceae). These two groups mainly differed in their tree densities and species richness, but concerning their plant species composition they were very similar. *Gliricidia sepium* (Fabaceae) characterized the group GG (*Gliricidia*-group) which was richest in species compared to the other groups. *Erythrina fusca* (Fabaceae) was rarely planted in this group. Further, high values of mean height and width indicated that live fences of this group were well structured. Another distinct group was TG (*Tectona*-group) dominated by *Tectona grandis* (Lamiaceae). This group comprised only two live fences of which one was found along a teak plantation and one within farmland. Probably, *Tectona grandis* was planted as timber source, but as teak plantations were rare in the study area and the extremely humid climate is not suitable for this species, this live fence type was not common in La Gamba. In drier reagions *Tectona grandis* is frequently used for live fences (GARGIULLO 2008).

Nearly one third of the investigated live fences were more or less unique in their species composition, being characterized by different species that were abundant in only one or few sites. These were summarized as MG (Mixed-group). MG represents a very heterogeneous assembly of live fences due to their inhomogenous species compositions and structural characteristics. A group specific, dominant species could not be figured out.

Statistical analysis showed that the *Erythrina*-dominated live fences, which were the most common ones, were significantly poorer in plant species than GG and MG. In order to improve the structure and species richness of live fences in La Gamba, tree species occurring in species rich groups, could be used to enrich species poor fences. Especially more species that provide fruits and flowers for wildlife should be introduced, or just not be removed if growing naturally.

6.3. Ecological value of landscape corridors and live fences

6.3.1. Landscape corridors and stepping stones

Agricultural landscapes in the Neotropics can maintain a considerable amount of the original biodiversity. Because forests are often highly fragmented within agricultural areas, stepping stones and corridors like gallery forests, live fences and remnant trees are very important for the maintenance of native plant and animal species because they provide habitats, food resources and they promote the movement of organisms between natural habitats (e.g. HARVEY ET AL. 2005, CHACÓN LEÓN AND HARVEY 2007, ESCOBEDO-MORALES AND MANDUJANO 2007, HARVEY ET AL. 2008b,c, SEAMAN AND SCHULZE 2009).

In La Gamba the agricultural area represents a considerable barrier for the exchange of organisms between the forest areas. In order to figure out zones of the landscape that are easiest passable for wildlife, nine corridor routes connecting the big forest patches were computed. The resulting corridors showed that remnants of riparian forests were very important landscape elements. One corridor followed a river and was accompanied by patches of riparian vegetation. In two parts of the study area, riparian forests extended from the forests into the farmland which significantly shortened the distance across agricultural areas. Along other corridor routes that traversed rivers (especially the Río Bonito), patches of natural riparian vegetation and forests were valuable stepping stones.

SEAMAN AND SCHULZE (2009) found that connected gallery forersts supported a greater number of forest-specialist species than isolated gallery forests and therefore were of greater conservation value. They suggested that the conservation value of isolated gallery forests could be improved by connecting them to networks of live fences and by revegetating bare river banks all the way to the next forest fragment. For species depending on closed forest, gallery forest can do little or nothing to ease their situation, but for forest generalists and non-forest species within anthropogenic ecosystems they provide important habitats.

Live fences played an important role as wildlife corridors, but only few were present along the computed corridors which primarily showed the shortest distances between forest areas. By elongating existing live fences or establishing new ones within or near the corridor zones and by improving their structure and plant species compositions, functional corridors across the agricultural landscape of La Gamba can be installed. Further, the presence of remnant trees in pastures is important too, especially for birds. In La Gamba more than one third of the pastureland was classified as arboreal pasture. Preserving or even increasing the tree cover in pastures is an important issue regarding the permeability of the landscape for wildlife.

Corridors can be a useful tool for biodiversity conservation and wildlife management. Animals have different preferences according landscape elements depending on their abilities and habitat selection. Therefore, behavioral processes should be included in studies on biological corridors (ROSENBERG ET AL. 1997, CHETKIEWICZ ET AL. 2006). For example, bats can be frequently found in riparian forests and live fences. Birds need a certain tree cover, but do not use live fences that frequently (HARVEY ET AL. 2008b). Bigger animals as howler monkeys need forest areas of a certain minimum size, while corridors play a minor role for their population sizes (ESCOBEDO-MORALES AND MANDUJANO 2007).

6.3.2. Live fences

Different studies confirmed that forest fragments, single trees and live fences are richer in species than the adjacent agricultural areas (e.g. HARVEY ET AL. 2008a). These landscape elements are of considerable value for natural species and landowners as well, because they serve as wind protection, protection of water, source of wood and fruits and they provide shadow for cattle (HARVEY ET AL. 2005, MORERA ET AL. 2007, HARVEY ET AL. 2008a,b).

The ecological value of line elements in La Gamba was assessed by a simple point system based on structural parameters. Live fences and roadside tree lines, which were the most numerous connecting line elements, had the lowest ecological value compared to the other (natural) connecting line elements. Both types were usually straight, narrow, little structured and species poor tree lines. Additionally, only few live fences were directly connected to forest areas. Although the results indicate a relatively poor corridor quality of live fences, they play an essential role for animals in open habitats. In previous studies many different animal and insect species using live fences were recorded among which not only generalists, but also several forest-depending species were found (e.g. HARVEY ET AL. 2005).

Animals use live fences as food resource, travel corridors and habitat. The presence of fruiting and flowering trees is of great importance for the ecological value of live fences. In La Gamba *Erythrina fusca* (Fabaceae) is valuable for many nectarivorous birds. *Inga spectabilis* (Fabaceae) is an important food source for many different animal species. Others like *Psidium guajava* (Myrtaceae) and species of the genus *Ficus* (Moraceae) are also important fruit trees. Many trees and treelets provide flowers for insects and birds. A higher diversity of plant species in live fences will certainly support a higher diversity of animals using live fences.

The management of live fences has strong effect on their species richness. HARVEY ET AL. (2005) pointed out that unpollarded live fences were richer in bird species and supported higher individual numbers of birds. Moreover, bird species richness was positively correlated to the mean diameter, height and crown diameter of live fences. In La Gamba live fences are usually pollarded completely, which means that all trees are pruned at a height of about 2 m. This causes enormous changes and disturbances for the plant and animal species using live fences, especially for those living in live fences.

HARVEY ET AL. (2005) proposed that live fences should be integrated into conservation planning in agricultural landscapes and figured out four opportunities to capitalize on their ecological roles. These are also sensible measures for improving the conservation value of live fences in La Gamba:

1) Increase of the total number and extend of live fences. This can be achieved by converting “dead” fences to live fences and by dividing pastures into smaller paddocks (e.g. for rotational cattle grazing which might also increase cattle production).

2) Improvement of floristic diversity by planting more tree and shrub species. Very valuable are species that provide fruits, flowers and foliage year round.

3) Placing and elongation of live fences so that they connect forests and other natural habitats. This would be a very effective way of enhancing the landscape connectivity for wildlife species (at least for those that use live fences as movement corridors).

4) More conservation friendly management practices, e.g. staggered or partial pollarding (in contrast to complete pollarding), less frequent pollarding and keeping trees at a taller height and wider crown width. This would lessen the grade of disturbance and allow the colonization of live fences by epiphytes, vines and lianas.

In addition, studies on movement and habitat selection of animal species would be very valuable to complement the results of this study and should be integrated into conservation planning.

In order to achieve the implementing of the given proposals the cooperation with the farmers is a central issue. It is essential to inform farmers about the ecological importance of live fences and about conservation friendly live fence management strategies. Additionally, payments would be necessary to compensate time, resources and labor that these strategies may entail and to reward farmers for their contribution to nature conservation (HARVEY ET AL. 2005).

The Tropical Station La Gamba already launched a project with the object to establish biological corridors at the edge of the “Rainforest of the Austrians” (which is part of the Piedras Blancas National Park) to support the migratory movements and genetic exchange of the various plant and animal species in the region. The aim of the project is to reforest parts of fincas with indigenous tree species (forest patches and riversides). Together with participating farmers a reforestation plan was developed and the Tropical Station provides information and young trees for the farmers (personal comment HUBER 2009).

7. CONCLUSIONS

Since its founding in the mid 1940s the agriculture in La Gamba has continuously expanded and has gone through considerable changes and trends. Cattle breeding has always been of great importance and pastures are still the most area consuming land use type comprising 61.07% of the agricultural area. The cultivation of rice has sharply declined (1.04% of agricultural area), while the cultivation of oil palms has increased rapidly and now is the second most important land use type covering 30.55% of the agricultural area. In recent times only small parts of natural forest have been cleared and nature conservation initiatives aim to protect the remaining forest areas of the region (Piedras Blancas National Park). Nevertheless, nearly all plain areas of the study area were cultivated while primary forests were restricted to steeper slopes. Further increase of agricultural production will lead to intensification of present cultivations and/or expansion to steeper slopes which would encompass the danger of soil degradation and loss of natural vegetation. Hence, the development and application of sustainable land use techniques are of great importance.

Landscape indices clearly illustrated that forests and rural areas differed in their structural characteristics. Forest areas consisted of big patches of similar patch type and included lesser linear landscape elements than rural areas. Rural sections showed high values of fractal dimension which point to a high complexity of landscape patches, but are probably caused by the high density of linear elements. The landscape metrics also revealed that oil palm plantations were generally bigger and simpler shaped than pastures. Hence, huge oil palm plantations can cause a simplification of the landscape structure within the agricultural area. As these plantations are very intensive and monotonous, their spreading will probably lead to the loss of natural habitats such as forest patches, single trees and live fences which are frequent within pastureland. This would entail a decrease of permeability of the cultivated area for wildlife.

As settlements and agriculture are severe movement barriers for wildlife, the presence of trees, live fences and natural landscape elements within farmland is important to facilitate the exchange of plants and animals between the big forest areas. Patches of riparian forests along the riversides are very valuable stepping stones that should be conserved. Live fences are positive examples of anthropogenic landscape elements that are valuable for farmers as well as for wildlife. However, compared to natural line elements such as forest strips, they were poorly structured and were of lower ecological value. The connectivity of live fences to forests was poor (13.07%), but nearly half of them (46.57%) were linked to other connecting line elements. By elongating isolated live fences the connectivity of natural habitats could be considerably improved.

The plant species richness of live fences at landscape scale was considerably high (92 species) compared to other anthropogenic ecosystems, but the diversity of individual fences was rather low with a mean of 9.0 species per site (50 m long sections of a live fence). The farmers normally use only a small set of different tree species for planting live fences. *Erythrina fusca* (Fabaceae) was by far the most frequent tree, although there would exist a lot of more suitable species. Several trees arising from natural regeneration, that are apparently appropriate live fence trees, could be planted in combination with the commonly used species, or at least should not be removed if growing naturally.

The classification of live fences showed that five different groups of live fences could be defined. These mainly differed in their dominant tree species while understorey plants showed little association to any group. Live fences dominated by *Erythrina fusca* (Fabaceae) were the most common type and formed two groups. Both were characterized by low species richness and relatively high tree densities. Another distinct group consisted of live fences dominated by *Gliricidia sepium* (Fabaceae) which were generally species rich and trees were relatively densely planted. One group was characterized by *Tectona grandis* (Lamiaceae) but it included only two live fences showing that teak was not important for live fences in La Gamba, although it is a valuable timber tree. The fifth group included live fences which were dominated by different tree species. The results show that the majority of live fences (*Erythrina*-dominated type) was species poor with mean of only 4.5 tree species per site, although in total a relatively great number of tree species (19) was planted in live fences and several further tree species grew naturally. Species poor live fences could be enriched with less commonly planted species such as *Bixa orellana* (Bixaceae), *Spondias mombin* (Anacardiaceae), *Inga spectabilies* (Fabaceae), *Crescentia cujete* (Bignoniaceae) and others.

Changes in life fence management can considerably enhance the structure of live fences without much reduction of farm production. Through the establishment of more live fences and the right management techniques, probably more animal species could use the fences as habitat or travel corridors. The usage of more plant species providing fruits and flowers would certainly have positive effects on wildlife. The computed corridor routes illustrate which parts of the study area are easiest passable for wildlife and provide a good basis for landscape planning concerning wildlife corridors. Beside corridors the tree cover of pastures is very important for wildlife as well (especially for birds). Hence, increasing the tree density within farmland by planting indigenous tree species would be an effective, low-cost strategy for improving the landscape structure.

In order to work out strategies for creating live fences of high ecological value, further studies on how different animal species use them and what plant species are important food sources would be very valuable. Additionally, the actual management strategies of the farmers and their requirements concerning live fences should be implicated when conservation friendly management techniques are to be developed.

ACKNOWLEDGEMENTS

First, I would like to thank my thesis advisors Dr. Georg Grabherr and Dr. Anton Weissenhofer for their support in developing the concept for this thesis and for the excellent coaching during the completion period. I am also very grateful to Mag. Stefan Schindler who assisted me with the program FRAGSTATS and the interpretation of the landscape metrics and who reviewed parts of the script. I also thank Dipl. Ing. Richard Hastik for his supportive instructions on how to compute the corridor routes with ArcGIS. Furthermore, I thank Marianela Baquero, Tobias Flatscher and my dear friend Ruth Flatscher for improving the language of some parts of the script. I also want to express gratitude to all the farmers and landowners in La Gamba who gave me permission to do investigations on their properties. Finally, I am very grateful to my family for their support for me and my study.

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APPENDIX I: Abbreviations

`	Minute
°	Degree
°C	Degree Celsius
APG	Angiosperm Phylogenetic Group
AREA	Mean patch area
C	Corridor
CAT	Category
CENIGA	Centro National de Información Geoambiental
CONTAG	Contagion index
ECON	Edge contras index
EDG	*Erythrina*-dense-group
EG	*Erythrina*-group
ENN	Euclidean Nearest Neighbor Distance
Fig.	Figure
GG	*Gliricidia*-group
ha	Hectare
ind.	Individual
km^2	Square kilometer
m	Meter
MG	Mixed-group
MINAET	Ministerio de Ambiente, Energía y Telecomunicaciones
mm	Millimeter
mn	Mean
Nr.	Number
p.	Page
PAFRAC	Fractal dimension
PD	Patch density
PNCB	Programa Nacional de Corredores Biológicos de Costa Rica
PRD	Patch richness density
SIMI	Similarity index
SINAC	Sistema Nacional de Áreas de Conservación
sp.	Species
Tab.	Table
TG	*Tectona*-group
U.F.Co.	United Fruit Company

APPENDIX II: Species list of investigation sites

Group EG					Site center coordinates [m]	
Site	Family	Genus	Species	Individuals	X	Y
1	Fabaceae	*Erythrina*	*fusca*	16	259,611	963,399
	Fabaceae	*Gliricidia*	*sepium*	1		
	Melastomataceae	*Conostegia*	*subcrustulata*	1		
	Piperaceae	*Piper*	*aduncum*	6		
2	Fabaceae	*Erythrina*	*fusca*	12	258,214	962,239
	Fabaceae	*Gliricidia*	*sepium*	1		
	Lauraceae	*Ocotea*	*leucoxylon*	1		
	Urticaceae	*Cecropia*	*peltata*	1		
3	Fabaceae	*Erythrina*	*fusca*	11	258,371	962,424
	Fabaceae	*Gliricidia*	*sepium*	2		
	Melastomataceae	*Miconia*	*schlimii*	1		
	Melastomataceae	*Miconia*	*trinervia*	1		
	Myrtaceae	*Psidium*	*guajava*	1		
4	Fabaceae	*Erythrina*	*fusca*	12	259,194	962,358
	Fabaceae	*Senna*	*reticulata*	1		
	Piperaceae	*Piper*	*aduncum*	6		
	Verbenaceae	*Lantana*	*trifolia*	3		
5	Dilleniaceae	*Doliocarpus*	*hispidus*	1	259,120	962,997
	Fabaceae	*Erythrina*	*fusca*	19		
	Lazistemaceae	*Lozania*	*pittieri*	1		
	Melastomataceae	*Miconia*	*schlimii*	1		
	Piperaceae	*Piper*	*aduncum*	1		
	Piperaceae	*Piper*	*hispidum*	9		
	Verbenaceae	*Lantana*	*camara*	2		
	Verbenaceae	*Lantana*	*trifolia*	4		
6	Fabaceae	*Erythrina*	*fusca*	16	258,421	964,036
	Hypericaceae	*Vismia*	*baccifera*	7		
	Melastomataceae	*Clidemia*	*crenulata*	12		
	Melastomataceae	*Miconia*	*schlimii*	10		
	Moraceae	*Ficus*	*insipida*	2		
	Piperaceae	*Piper*	*aduncum*	1		
	Piperaceae	*Piper*	*hispidum*	4		
	Piperaceae	*Piper*	*peltatum*	2		
	Salicaceae	*Casearia*	*arborea*	1		
	Solanaceae	*Solanum*	*antillarum*	1		
7	Fabaceae	*Erythrina*	*fusca*	15	259,834	962,491
	Fabaceae	*Gliricidia*	*sepium*	1		
	Melastomataceae	*Miconia*	*schlimii*	4		
	Moraceae	*Ficus*	*costaricana*	1		
	Salicaceae	*Casearia*	*arborea*	3		
	Solanaceae	*Witheringia*	*mortonii*	1		
	undetermined	*undetermined*	*undetermined*	4		
8	Asteraceae	*Vernonia*	*patens*	2	259,577	961,375
	Dilleniaceae	*Doliocarpus*	*hispidus*	11		
	Euphorbiaceae	*Alchornea*	*costaricensis*	3		
	Fabaceae	*Andira*	*inermis*	1		
	Fabaceae	*Erythrina*	*fusca*	10		
	Fabaceae	*Inga*	*spectabilis*	3		
	Hypericaceae	*Vismia*	*baccifera*	3		
	Lamiaceae	*Gmelina*	*arborea*	1		
	Melastomataceae	*Clidemia*	*crenulata*	14		

APPENDIX II (continued)

Group EG					Site center coordinates [m]	
Site	Family	Genus	Species	Individuals	X	Y
8	Melastomataceae	*Miconia*	*schlimii*	6	259,577	961,375
	Myristicaceae	*Compsoneura*	*sprucei*	1		
	Myrtaceae	*Syzygium*	*malaccense*	10		
	Piperaceae	*Piper*	*aduncum*	1		
	Piperaceae	*Piper*	*hispidum*	1		
	Salicaceae	*Casearia*	*arborea*	2		
	Verbenaceae	*Lantana*	*camara*	1		
9	Fabaceae	*Erythrina*	*fusca*	14	259,776	961,996
	Lauraceae	*Ocotea*	*sp.*	1		
	Melastomataceae	*Clidemia*	*crenulata*	3		
	Melastomataceae	*Miconia*	*schlimii*	11		
	Moraceae	*Ficus*	*insipida*	1		
	Piperaceae	*Piper*	*aduncum*	1		
	Piperaceae	*Piper*	*hispidum*	2		
	Piperaceae	*Piper*	*peltatum*	3		
	Salicaceae	*Casearia*	*arborea*	1		
10	Fabaceae	*Erythrina*	*fusca*	24	259,875	962,131
	Gesneriaceae	*Drymonia*	*macrophylla*	2		
	Melastomataceae	*Conostegia*	*subcrustulata*	1		
	Moraceae	*Ficus*	*maxima*	2		
	Salicaceae	*Casearia*	*arborea*	1		
11	Euphorbiaceae	*Alchornea*	*costaricensis*	1	259,399	963,630
	Fabaceae	*Erythrina*	*fusca*	12		
	Melastomataceae	*Miconia*	*schlimii*	14		
	Myrtaceae	*Syzygium*	*jambos*	1		
	Piperaceae	*Piper*	*aduncum*	3		
	Piperaceae	*Piper*	*auritum*	5		
	Piperaceae	*Piper*	*hispidum*	4		
	Piperaceae	*Piper*	*peltatum*	1		
	Salicaceae	*Casearia*	*arborea*	1		
	Urticaceae	*Cecropia*	*insignis*	3		
	Verbenaceae	*Lantana*	*camara*	3		
	Verbenaceae	*Lantana*	*trifolia*	1		
12	Fabaceae	*Erythrina*	*fusca*	15	258,795	965,014
	Lauraceae	*Ocotea*	*mollifolia*	1		
	Melastomataceae	*Miconia*	*argentea*	1		
	Melastomataceae	*Miconia*	*trinervia*	1		
	Myrtaceae	*Syzygium*	*jambos*	1		
	Piperaceae	*Piper*	*hispidum*	1		
	Salicaceae	*Casearia*	*arborea*	4		
13	Fabaceae	*Erythrina*	*fusca*	19	258,509	964,231
	Piperaceae	*Piper*	*aduncum*	1		
	Verbenaceae	*Lantana*	*camara*	1		
14	Fabaceae	*Erythrina*	*fusca*	27	261,141	964,613
	Melastomataceae	*Clidemia*	*crenulata*	2		
	Piperaceae	*Piper*	*hispidum*	1		
15	Fabaceae	*Erythrina*	*fusca*	13	261,073	964,500
	Salicaceae	*Casearia*	*arborea*	3		
16	Dilleniaceae	*Davilla*	*kunthii*	2	261,027	964,462
	Fabaceae	*Erythrina*	*fusca*	11		
	Melastomataceae	*Miconia*	*schlimii*	2		

APPENDIX II (continued)

Group EG					Site center coordinates [m]	
Site	Family	Genus	Species	Individuals	X	Y
16	Piperaceae	*Piper*	*hispidum*	2	261,027	964,462
	Salicaceae	*Casearia*	*arborea*	3		
17	Fabaceae	*Erythrina*	*fusca*	22	259,485	964,028
	Melastomataceae	*Clidemia*	*crenulata*	1		
	Melastomataceae	*Conostegia*	*subcrustulata*	3		
	Melastomataceae	*Miconia*	*argentea*	10		
	Melastomataceae	*Miconia*	*schlimii*	13		
	Piperaceae	*Piper*	*aduncum*	1		
	Piperaceae	*Piper*	*hispidum*	10		
	Salicaceae	*Casearia*	*arborea*	4		
18	Fabaceae	*Erythrina*	*fusca*	19	259,714	964,189
	Fabaceae	*Senna*	*reticulata*	5		
	Piperaceae	*Piper*	*hispidum*	1		
19	Anacardiaceae	*Spondias*	*mombin*	1	257,591	965,000
	Fabaceae	*Erythrina*	*fusca*	10		
	Myrtaceae	*Psidium*	*guajava*	3		
	Piperaceae	*Piper*	*aduncum*	7		
	Piperaceae	*Piper*	*hispidum*	2		
	Verbenaceae	*Lantana*	*camara*	5		
20	Fabaceae	*Erythrina*	*fusca*	14	258,219	964,900
	Fabaceae	*Inga*	*spectabilis*	1		
	Melastomataceae	*Conostegia*	*subcrustulata*	1		
	Piperaceae	*Piper*	*hispidum*	10		
	Piperaceae	*Piper*	*peltatum*	5		
	Solanaceae	*Solanum*	*chrysotrichum*	7		

Group EDG					Site center coordinates [m]	
Site	Family	Genus	Species	Individuals	X	Y
21	Fabaceae	*Erythrina*	*fusca*	47	259,084	963,894
	Salicaceae	*Casearia*	*arborea*	2		
22	Fabaceae	*Erythrina*	*fusca*	38	259,803	961,845
	Piperaceae	*Piper*	*peltatum*	4		
23	Fabaceae	*Erythrina*	*fusca*	59	259,817	961,724
	Melastomataceae	*Miconia*	*schlimii*	5		
	Myristicaceae	*Compsoneura*	*sprucei*	1		
	Piperaceae	*Piper*	*hispidum*	2		
	Salicaceae	*Casearia*	*arborea*	5		
24	Fabaceae	*Erythrina*	*fusca*	44	259,859	962,220
	Melastomataceae	*Miconia*	*schlimii*	2		
	Myrtaceae	*Psidium*	*guajava*	1		

Group GG					Site center coordinates [m]	
Site	Family	Genus	Species	Individuals	X	Y
25	Calophyllaceae	*Calophyllum*	*brasiliense*	2	258,615	964,275
	Fabaceae	*Erythrina*	*fusca*	10		
	Fabaceae	*Gliricidia*	*sepium*	11		
	Lamiaceae	*Gmelina*	*arborea*	17		
	Lamiaceae	*Vitex*	*cooperi*	1		
	Melastomataceae	*Conostegia*	*subcrustulata*	3		
	Melastomataceae	*Miconia*	*trinervia*	1		

APPENDIX II (continued)

Group GG					Site center coordinates [m]	
Site	Family	Genus	Species	Individuals	X	Y
25	Myrtaceae	*Psidium*	*guajava*	2	258,615	964,275
26	Combretaceae	*Terminalia*	*amazonia*	2	259,854	961,788
	Fabaceae	*Erythrina*	*fusca*	4		
	Fabaceae	*Gliricidia*	*sepium*	9		
	Malpighiaceae	*Hiraea*	*fagifolia*	1		
	Melastomataceae	*Clidemia*	*crenulata*	1		
	Melastomataceae	*Miconia*	*schlimii*	17		
	Moraceae	*Ficus*	*bullenii*	1		
	Moraceae	*Ficus*	*colubrinae*	1		
	Rutaceae	*Citrus*	*sinensis*	3		
27	Dilleniaceae	*Doliocarpus*	*multiflorus*	1	257,034	964,698
	Euphorbiaceae	*Alchornea*	*costaricensis*	1		
	Fabaceae	*Erythrina*	*fusca*	1		
	Fabaceae	*Gliricidia*	*sepium*	8		
	Melastomataceae	*Miconia*	*argentea*	1		
	Melastomataceae	*Miconia*	*impetiolaris*	1		
	Melastomataceae	*Miconia*	*schlimii*	3		
	Phyllantaceae	*Hyeronima*	*alchorneoides*	2		
	Salicaceae	*Casearia*	*arborea*	1		
	Urticaceae	*Cecropia*	*peltata*	1		
28	Asteraceae	*Vernonia*	*patens*	2	256,934	964,626
	Fabaceae	*Gliricidia*	*sepium*	4		
	Hypericaceae	*Vismia*	*baccifera*	5		
	Melastomataceae	*Miconia*	*impetiolaris*	2		
	Melastomataceae	*Miconia*	*schlimii*	5		
	Moraceae	*Ficus*	*maxima*	1		
	Piperaceae	*Piper*	*hispidum*	5		
	Polygonaceae	*Coccoloba*	*obovata*	1		
	Rubiaceae	*Sabicea*	*villosa*	4		
	Salicaceae	*Casearia*	*arborea*	1		
	Urticaceae	*Cecropia*	*peltata*	1		
	Verbenaceae	*Lantana*	*camara*	1		
	Verbenaceae	*Lantana*	*trifolia*	1		
29	Bignoniaceae	*Crescentia*	*cujete*	2	258,165	974,572
	Fabaceae	*Erythrina*	*fusca*	3		
	Fabaceae	*Gliricidia*	*sepium*	8		
	Hypericaceae	*Vismia*	*baccifera*	3		
	Melastomataceae	*Conostegia*	*subcrustulata*	2		
	Melastomataceae	*Miconia*	*schlimii*	2		
	Moraceae	*Ficus*	*insipida*	1		
	Rutaceae	*Citrus*	*sinensis*	1		
	Salicaceae	*Casearia*	*arborea*	2		
30	Fabaceae	*Erythrina*	*fusca*	1	258,448	964,401
	Fabaceae	*Gliricidia*	*sepium*	8		
	Lamiaceae	*Tectona*	*grandis*	1		
	Melastomataceae	*Miconia*	*schlimii*	15		
	Piperaceae	*Piper*	*auritum*	1		
	Piperaceae	*Piper*	*hispidum*	1		
31	Annonaceae	*Cymbopetalum*	*costaricense*	16	258,597	962,126
	Dilleniaceae	*Davilla*	*kunthii*	2		
	Euphorbiaceae	*Cnidoscolus*	*aconitifolius*	1		

APPENDIX II (continued)

Group GG					Site center coordinates [m]	
Site	Family	Genus	Species	Individuals	X	Y
31	Fabaceae	*Gliricidia*	*sepium*	7	258,597	962,126
	Fabaceae	*Senna*	*reticulata*	3		
	Lamiaceae	*Vitex*	*cooperi*	1		
	Melastomataceae	*Clidemia*	*crenulata*	8		
	Melastomataceae	*Conostegia*	*subcrustulata*	12		
	Melastomataceae	*Miconia*	*argentea*	2		
	Melastomataceae	*Miconia*	*schlimii*	22		
	Moraceae	*Ficus*	*insipida*	2		
	Myrtaceae	*Psidium*	*guajava*	1		
	Piperaceae	*Piper*	*hispidum*	8		
	Piperaceae	*Piper*	*peltatum*	4		
	Rubiaceae	*Palicourea*	*guianensis*	11		
	Rutaceae	*Amyris*	*brenesii*	2		
	Salicaceae	*Casearia*	*arborea*	10		
	Verbenaceae	*Lantana*	*trifolia*	1		
32	Fabaceae	*Erythrina*	*fusca*	1	258,745	962,071
	Fabaceae	*Gliricidia*	*sepium*	5		
	Loranthaceae	*Struthanthus*	*leptostachyus*	1		
	Melastomataceae	*Miconia*	*schlimii*	1		
	Piperaceae	*Piper*	*peltatum*	1		
	Rutaceae	*Citrus*	*sinensis*	2		
	Salicaceae	*Casearia*	*arborea*	9		
	Theophrastaceae	*Clavija*	*costaricana*	1		
	undetermined	*undetermined*	*undetermined*	3		
33	Fabaceae	*Erythrina*	*fusca*	1	258,696	961,907
	Fabaceae	*Gliricidia*	*sepium*	15		
	Melastomataceae	*Conostegia*	*subcrustulata*	4		
	Melastomataceae	*Miconia*	*argentea*	1		
	Melastomataceae	*Miconia*	*schlimii*	9		
	Melastomataceae	*Miconia*	*trinervia*	2		
	Piperaceae	*Piper*	*hispidum*	1		
	Rutaceae	*Citrus*	*sinensis*	5		
	Salicaceae	*Casearia*	*arborea*	1		
	Verbenaceae	*Lantana*	*camara*	2		
34	Asteraceae	*Neurolaena*	*lobata*	1	258,694	961,926
	Bixaceae	*Bixa*	*orellana*	1		
	Fabaceae	*Erythrina*	*fusca*	2		
	Fabaceae	*Gliricidia*	*sepium*	8		
	Lamiaceae	*Tectona*	*grandis*	2		
	Melastomataceae	*Conostegia*	*subcrustulata*	3		
	Melastomataceae	*Miconia*	*schlimii*	3		
	Passifloraceae	*Passiflora*	*quadrangularis*	1		
	Piperaceae	*Piper*	*peltatum*	1		
	Rutaceae	*Citrus*	*sinensis*	4		
	Salicaceae	*Casearia*	*arborea*	8		
35	Fabaceae	*Gliricidia*	*sepium*	8	257,144	965,110
	Hypericaceae	*Vismia*	*baccifera*	20		
	Loranthaceae	*Oryctanthus*	*alveolotus*	1		
	Melastomataceae	*Clidemia*	*crenulata*	6		
	Melastomataceae	*Miconia*	*argentea*	1		
	Melastomataceae	*Miconia*	*impetiolaris*	9		

APPENDIX II (continued)

Group GG					Site center coordinates [m]	
Site	**Family**	**Genus**	**Species**	**Individuals**	**X**	**Y**
35	Piperaceae	*Piper*	*aduncum*	7	257,144	965,110
	Piperaceae	*Piper*	*hispidum*	7		
	Verbenaceae	*Lantana*	*camara*	4		

Group TG					Site center coordinates [m]	
Site	**Family**	**Genus**	**Species**	**Individuals**	**X**	**Y**
36	Fabaceae	*Erythrina*	*fusca*	4	259,794	962,956
	Fabaceae	*Gliricidia*	*sepium*	1		
	Lamiaceae	*Tectona*	*grandis*	11		
	Melastomataceae	*Conostegia*	*subcrustulata*	1		
	Myrtaceae	*Psidium*	*guajava*	2		
	Salicaceae	*Casearia*	*arborea*	2		
	Verbenaceae	*Lantana*	*trifolia*	1		
37	Asteraceae	*Clibadium*	*glomeratum*	1	260,735	963,927
	Boraginaceae	*Cordia*	*spinescens*	7		
	Lamiaceae	*Tectona*	*grandis*	13		
	Melastomataceae	*Clidemia*	*crenulata*	4		
	Melastomataceae	*Conostegia*	*subcrustulata*	44		
	Myrtaceae	*Psidium*	*guajava*	1		
	Piperaceae	*Piper*	*hispidum*	11		
	Piperaceae	*Piper*	*peltatum*	2		
	Salicaceae	*Casearia*	*arborea*	1		
	Solanaceae	*Solanum*	*sessiliflorum*	1		
	Urticaceae	*Cecropia*	*insignis*	1		
	Verbenaceae	*Lantana*	*trifolia*	1		

Group MG					Site center coordinates [m]	
Site	**Family**	**Genus**	**Species**	**Individuals**	**X**	**Y**
38	Combretaceae	*Terminalia*	*amazonia*	10	259,862	961,954
	Fabaceae	*Erythrina*	*fusca*	6		
	Fabaceae	*Inga*	*spectabilis*	3		
	Hypericaceae	*Vismia*	*baccifera*	2		
	Malpighiaceae	*Hiraea*	*fagifolia*	2		
	Melastomataceae	*Miconia*	*argentea*	2		
	Melastomataceae	*Miconia*	*schlimii*	7		
	Moraceae	*Ficus*	*maxima*	1		
	Myristicaceae	*Compsoneura*	*sprucei*	1		
	Rutaceae	*Citrus*	*sinensis*	1		
	Salicaceae	*Casearia*	*arborea*	1		
	Sapindaceae	*Vouarana*	*guianensis*	2		
39	Fabaceae	*Erythrina*	*fusca*	8	258,471	964,667
	Fabaceae	*Senna*	*reticulata*	3		
	Melastomataceae	*Conostegia*	*subcrustulata*	2		
	Piperaceae	*Piper*	*hispidum*	3		
	Piperaceae	*Piper*	*peltatum*	1		
40	Anacardiaceae	*Spondias*	*mombin*	1	258,416	964,006
	Fabaceae	*Erythrina*	*fusca*	2		
	Malvaceae	*Theobroma*	*cacao*	20		
	Moraceae	*Ficus*	*insipida*	8		
	Myrtaceae	*Psidium*	*guajava*	2		
	Salicaceae	*Casearia*	*arborea*	2		

APPENDIX II (continued)

Group MG					Site center coordinates [m]	
Site	**Family**	**Genus**	**Species**	**Individuals**	**X**	**Y**
41	Asparagaceae	*Dracaena*	*(fragrans)*	1	256,604	963,929
	Bignoniaceae	*Crescentia*	*cujete*	2		
	Fabaceae	*Erythrina*	*fusca*	1		
	Fabaceae	*Gliricidia*	*sepium*	2		
	Melastomataceae	*Clidemia*	*crenulata*	1		
	Melastomataceae	*Conostegia*	*subcrustulata*	5		
	Melastomataceae	*Miconia*	*argentea*	1		
	Melastomataceae	*Miconia*	*schlimii*	1		
	Myristicaceae	*Compsoneura*	*sprucei*	1		
	Myrtaceae	*Psidium*	*guajava*	1		
	Myrtaceae	*Syzygium*	*malaccense*	1		
	Piperaceae	*Piper*	*hispidum*	3		
	Piperaceae	*Piper*	*peltatum*	2		
	Solanaceae	*Solanum*	*chrysotrichum*	3		
	Verbenaceae	*Lantana*	*camara*	2		
42	Euphorbiaceae	*Alchornea*	*costaricensis*	2	256,613	963,925
	Euphorbiaceae	*Croton*	*pictum*	1		
	Loranthaceae	*Struthanthus*	*leptostachyus*	1		
	Melastomataceae	*Conostegia*	*subcrustulata*	4		
	Melastomataceae	*Miconia*	*schlimii*	7		
	Myristicaceae	*Compsoneura*	*sprucei*	2		
	Myrtaceae	*Psidium*	*guajava*	3		
	Piperaceae	*Piper*	*hispidum*	6		
	Piperaceae	*Piper*	*peltatum*	6		
	Verbenaceae	*Lantana*	*trifolia*	4		
43	Asteraceae	*Clibadium*	*anceps*	4	260,617	963,945
	Fabaceae	*Senna*	*reticulata*	15		
	Heliconiaceae	*Heliconia*	*latispatha*	3		
	Heliconiaceae	*Heliconia*	*wagneriana*	1		
	Malvaceae	*Sida*	*martiana*	6		
	Marantaceae	*Calathea*	*luthea*	7		
	Melastomataceae	*Clidemia*	*crenulata*	2		
	Melastomataceae	*Conostegia*	*subcrustulata*	7		
	Melastomataceae	*Miconia*	*schlimii*	2		
	Moraceae	*Ficus*	*insipida*	4		
	Myrtaceae	*Psidium*	*guajava*	2		
	Piperaceae	*Piper*	*aduncum*	4		
	Piperaceae	*Piper*	*hispidum*	19		
	Piperaceae	*Piper*	*peltatum*	2		
	Salicaceae	*Casearia*	*arborea*	4		
	Urticaceae	*Cecropia*	*peltata*	9		
	Verbenaceae	*Lantana*	*camara*	1		
	Verbenaceae	*Lantana*	*trifolia*	4		
44	Apocynaceae	*Allamanda*	*cathartica*	1	261,414	964,157
	Asteraceae	*Vernonia*	*patens*	1		
	Dilleniaceae	*Davilla*	*kunthii*	11		
	Fabaceae	*Mimosa*	*pigra*	2		
	Heliconiaceae	*Heliconia*	*latispatha*	9		
	Marantaceae	*Calathea*	*luthea*	5		
	Melastomataceae	*Miconia*	*argentea*	7		
	Moraceae	*Ficus*	*insipida*	1		

APPENDIX II (continued)

Group MG					Site center coordinates [m]	
Site	Family	Genus	Species	Individuals	X	Y
44	Myrtaceae	*Psidium*	*guajava*	1	261,414	964,157
	Piperaceae	*Piper*	*aduncum*	24		
	Piperaceae	*Piper*	*hispidum*	4		
	Verbenaceae	*Lantana*	*camara*	5		
45	Boraginaceae	*Cordia*	*spinescens*	1	258,634	962,298
	Melastomataceae	*Clidemia*	*capitelata*	6		
	Melastomataceae	*Conostegia*	*subcrustulata*	3		
	Melastomataceae	*Miconia*	*schlimii*	2		
	Myrtaceae	*Psidium*	*guajava*	5		
	Piperaceae	*Piper*	*aduncum*	6		
	Piperaceae	*Piper*	*hispidum*	8		
	Rubiaceae	*Sabicea*	*villosa*	8		
	Verbenaceae	*Lantana*	*camara*	2		
46	Annonaceae	*Cymbopetalum*	*costaricense*	3	259,376	963,121
	Asteraceae	*Vernonia*	*patens*	1		
	Bignoniaceae	*Crescentia*	*cujete*	6		
	Fabaceae	*Erythrina*	*fusca*	4		
	Fabaceae	*Inga*	*spectabilis*	1		
	Melastomataceae	*Conostegia*	*subcrustulata*	4		
	Melastomataceae	*Miconia*	*schlimii*	6		
	Piperaceae	*Piper*	*hispidum*	1		
	Piperaceae	*Piper*	*peltatum*	1		
	Rubiaceae	*Hamelia*	*patens*	1		
	Verbenaceae	*Citharexylum*	*cf. viridi*	2		
	Verbenaceae	*Lantana*	*camara*	7		
47	Annonaceae	*Guatteria*	*amplifolia*	1	261,898	964,082
	Asteraceae	*Vernonia*	*patens*	2		
	Cyclanthaceae	*Carludovica*	*drudei*	1		
	Dilleniaceae	*Davilla*	*kunthii*	4		
	Euphorbiaceae	*Alchornea*	*costaricensis*	2		
	Fabaceae	*Inga*	*spectabilis*	13		
	Heliconiaceae	*Heliconia*	*latispatha*	2		
	Melastomataceae	*Conostegia*	*subcrustulata*	16		
	Melastomataceae	*Miconia*	*schlimii*	5		
	Myrtaceae	*Psidium*	*guajava*	3		
	Piperaceae	*Piper*	*aduncum*	3		
	Rubiaceae	*Hamelia*	*patens*	3		
	Urticaceae	*Cecropia*	*peltata*	9		
	Urticaceae	*Myriocarpa*	*longipes*	3		
48	Anacardiaceae	*Spondias*	*mombin*	1	257,470	965,103
	Chrysobalanaceae	*Licania*	*platypus*	1		
	Fabaceae	*Erythrina*	*fusca*	3		
	Hypericaceae	*Vismia*	*baccifera*	9		
	Melastomataceae	*Clidemia*	*crenulata*	2		
	Myrtaceae	*Psidium*	*guajava*	10		
	Piperaceae	*Piper*	*hispidum*	2		
	Piperaceae	*Piper*	*peltatum*	1		
	Salicaceae	*Casearia*	*arborea*	1		
49	Fabaceae	*Erythrina*	*fusca*	4	259,793	963,996
	Fabaceae	*Inga*	*spectabilis*	1		
	Melastomataceae	*Miconia*	*schlimii*	3		

APPENDIX II (continued)

Group MG					Site center coordinates [m]	
Site	Family	Genus	Species	Individuals	X	Y
49	Myrtaceae	*Syzygium*	*jambos*	11	259,793	963,996
	Piperaceae	*Piper*	*hispidum*	1		
	Salicaceae	*Casearia*	*arborea*	3		
	Urticaceae	*Cecropia*	*insignis*	1		
50	Euphorbiaceae	*Croton*	*schiedeanus*	1	259,608	963,977
	Fabaceae	*Erythrina*	*fusca*	4		
	Fabaceae	*Zygia*	*longifolia*	2		
	Melastomataceae	*Miconia*	*argentea*	2		
	Melastomataceae	*Miconia*	*schlimii*	16		
	Moraceae	*Ficus*	*costaricana*	1		
	Moraceae	*Ficus*	*citrifolia*	1		
	Myrtaceae	*Syzygium*	*jambos*	4		
	Piperaceae	*Piper*	*hispidum*	6		
	Salicaceae	*Casearia*	*arborea*	6		
	Simaroubaceae	*Quassia*	*armara*	1		
51	Bixaceae	*Bixa*	*orellana*	15	256,893	965,018
	Fabaceae	*Erythrina*	*fusca*	8		
	Fabaceae	*Inga*	*spectabilis*	2		
	Lamiaceae	*Gmelina*	*arborea*	10		
	Melastomataceae	*Clidemia*	*crenulata*	2		
	Myrtaceae	*Psidium*	*guajava*	10		
52	Annonaceae	*Guatteria*	*chiriquiensis*	3	259,902	964,106
	Euphorbiaceae	*Alchornea*	*costaricensis*	1		
	Melastomataceae	*Miconia*	*argentea*	5		
	Melastomataceae	*Miconia*	*schlimii*	18		
	Moraceae	*Ficus*	*maxima*	5		
	Piperaceae	*Piper*	*hispidum*	2		
	Salicaceae	*Casearia*	*arborea*	4		
53	Fabaceae	*Erythrina*	*fusca*	10	258,101	964,808
	Fabaceae	*Senna*	*reticulata*	30		
	Lamiaceae	*Tectona*	*grandis*	2		
	Piperaceae	*Piper*	*peltatum*	5		
54	Euphorbiaceae	*Sapium*	*laurifolium*	1	259,232	964,013
	Fabaceae	*Zygia*	*longifolia*	3		
	Hypericaceae	*Vismia*	*baccifera*	2		
	Melastomataceae	*Clidemia*	*crenulata*	7		
	Melastomataceae	*Miconia*	*argentea*	2		
	Melastomataceae	*Miconia*	*schlimii*	13		
	Myrtaceae	*Syzygium*	*jambos*	2		
	Piperaceae	*Piper*	*aduncum*	3		
	Piperaceae	*Piper*	*hispidum*	4		
	Salicaceae	*Casearia*	*arborea*	8		
	Simaroubaceae	*Quassia*	*armara*	3		

WGS 1984, UTM Zone 17N

False easting: 500,000

False northing: 0

Central meridian: -81

Scale factor: 0.9996

APPENDIX III: Photographs of different land use types, live fences and plant species

View on the agricultural landscape near the Tropical Station La Gamba.

Abandoned pastureland near the Tropical Station La Gamba.

Recently planted oil palm plantation at the border to the Piedras Blancas National Park.

Riparian vegetation dominated by *Gynerium sagittatum* (Poacaeae) at the Río Bonito.

River Quebrada Bolsa (Valle Bolsa).

Pastureland without trees (Valle Bonito).

Oil palm plantation at steep slope (Valle Bonito).

Settlement in the Valle Bonito near La Gamba.

Arboreal pasture (background) and pasture without trees (foreground) in the Valle Bonito.

Pastureland with isolated trees (Valle Bonito).

Rice field (Valle Bonito).

Swampy area dominated by the fern *Nephrolepis multiflora* (Oleandraceae).

Regularily pollarded live fence consisting mainly of *Erythrina fusca* (EG).

Live fence dominated by *Erythrina fusca* (MG), not pollarded regularly.

Live fence characterized by *Gliricidia sepium* and *Miconia schlimii* (GG).

Live fence with high density of *Erythrina fusca* trees, not pollarded regularly (EDG).


Dense live fence harboring species of *Helicona* (MG).


Live fence dominated by Teak - *Tectona grandis* (TG).


Transportation of harvested oil palm fruits by bullock kart.


View on abandoned pastureland with the Fila Costeña in the background.


Compound leave of *Erythrina fusca* (Fabaceae).


Branch of *Psidium guajava* (Myrtaceae).


Leaves of *Cresentia cujete* (Bignoniaceae).


Branch with typically elongated inflorescences of *Piper aduncum* (Piperaceae).

Curriculum vitae

Personal information

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Date of birth:	08.08.1986
Place of birth:	3830 Waidhofen/Thaya, Austria
Nationality:	Austria

Education

1992 - 1996	Primary school in Waidhofen/Thaya, Austria.
1996 - 2004	Secondary school in Waidhofen/Thaya, Austria.
2004 - 2010	Study of Biology at the University of Vienna, Austria.

Visits abroad/Practical trainings

Feb. 2007	2 weeks of botanical project study in Costa Rica.
Dec. 08 to Feb. 09	3 month stay at the Tropical Station La Gamba, Costa Rica in order to realize the field work for my diploma thesis. Mapping of land use and investigation of biological corridors.
Aug. 2009	Field course in Indonesia in cooperation with the University of Bogor - Institut Pertanian Bogor: Investigation of bird communities on Kraktau archipelago, in the Ujung Kulon National Park and Halimun National Park.

Computer skills

Microsoft Works
ArcGIS - Geographical Information System
Statistical programs: Statistica and R
Adobe Photoshop and Illustrator

Language knowledge

<u>German</u>:	mother tongue
<u>English</u>:	very good knowledge
<u>Spanish</u>:	good knowledge
<u>Hindi</u>:	basic knowledge
<u>French</u>:	basic knowledge