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CARBON STOCKS AND ECOLOGICAL IMPLICATIONS OF OPEN SPACES – A CASE STUDY IN RECIFE - BRAZIL

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I love you!

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SUMMARY

The aim of this work is to evaluate the ecological implications of the whole range of urban and rural land use systems from a common perspective focused on carbon stocks and land use change (LUC) in urbanizing areas of Recife in Brazil. To analyze the open spaces (OS), 22 representative experimental areas were defined, that represent 6 experimental systems identified in the urban to rural transect; natural forest, fallow land, perennial crops, annual crops, recreation areas and street trees. A common methodological approach was applied to all systems during a 24 month survey composed of field measurements and personal interviews on a household/farm level between 2005 and 2006. The structural composition, carbon stocks, biodiversity, indicators of resilience (Ri) and cooling potential were analyzed and projected to 6 case studies representing typical landscapes undergoing rapid changes in the peri-urban fringe of Recife. A social profile was drawn to support the understanding of the LUC process on a household/farm level and enable the creation of a scenario in which carbon stocks are kept neutral in the rural to urban LUC process, maintaining functions of OS to their users. The parameters analyzed undergo a huge variation across the experimental systems which distribution in turn undergoes a huge variation across the case studies. Recreation areas stored almost half of the carbon (24,23 t/ha) than natural forest fragments (48,33 t/ha) and perennial crops (61,77 t/ha) but had the highest Ri (206) and plant diversity (62 species). In densely populated areas the income generating functions of OS are reduced, resulting in proportionally more fallow land (50%) than in less populated areas (13,07%) and the extinction of natural forest fragments on a household level. The importance of perennial crops is almost maintained from 35% to 29% due to their role in supporting subsistence in poor households. Considering the functionality of OS across the study area, a distribution of 23% build-up, 18% natural forest, 24% perennial crops, 19% annual crops and 16% recreation area could compensate the carbon stocks reduced during the urbanization process. Any further reduction of OS would implicate in a compromise of functions to the settlers and/or carbon stocks. Finally are discussed the (i) ecological implications of the land-use systems; (ii) the implications of LUC; (iii) a future outlook about Emergy analysis and sustainability; and (iv) a prospective/strategic open space planning approach for the peri-urban fringe of megacities.

ZUSAMMENFASSUNG

Ziel der vorliegenden Dissertation war es, die unterschiedlichen Landnutzungssysteme in der ruralen und urbanen Landschaft von Recife - Brasilien methodisch einheitlich zu bearbeiten und besonders deren Potential als Kohlenstoffspeicher und die Einflüsse auf den Landnutzungswandel (LNW) zu bewerten. Es wurden insgesamt 22 Versuchsflächen selektiert, die es ermöglichten, daraus sechs typische Agro-Ökosysteme zu definieren, die typische im LNW befindliche Landschaften des peri-urbanen Recifes repräsentieren und als Fallstudien analysiert wurden (Waldflächen, Ruderalflächen, Dauerkulturen, annuelle Kulturen, parkähnliche Erholungsflächen und Straßenbäume). Von 2005 bis 2006 wurden in einem 24 monatigen Feldversuch die strukturelle Beschaffenheit der Ökosysteme, der Kohlenstoffspeicher, die Biodiversität sowie Indikatoren für Resilienz (Ri) und das Kühlungspotential erhoben. Um die Entscheidungsprozesse verstehen und analysieren zu können, erfolgten zusätzlich direkte Befragungen nach einem sozialen Bewertungssystem. Die analysierten Parameter präsentieren eine starke Variation zwischen den einzelnen Landnutzungssystemen. Erholungsflächen speichern lediglich 24,23 t/ha Kohlenstoff im Vergleich zu 48,33 t/ha in Waldflächen und 61,77 t/ha bei Dauerkulturen, weisen aber den höchsten Ri – Index (206) und die reichste Pflanzenvielfalt (62 Arten) auf. In dicht besiedelten Gegenden ist die ökonomische Bedeutung von FF reduziert, was durch einen verhältnismäßig großen Anteil von Ruderalflächen (50%) im Vergleich zu dünner besiedelten Gegenden (13,07%) verdeutlicht wird. Waldflächen verschwinden in rein urbanen Siedlungen, während Dauerkulturen ihre Bedeutung so gut wie erhalten (von 35 zu 29% der FF). Eine Verteilung von 23% bebauter Fläche, 18% Waldfläche, 24% Dauerkulturen, 19% annuelle Kulturen und 16% Erholungsflächen könnte den Kohlenstoff-Speicherverlust im Urbanisierungsprozess ausgleichen. Jede weitere Reduzierung der FF würde negative Veränderungen in der Funktionalität für deren Nutzer sowie ihres Potentials als Kohlenstoffspeicher bedeuten. Abschließend werden thesenhaft diskutiert: (i) die ökologische Wertigkeit der Landnutzungssysteme; (ii) sozio-ökonomische Einflüsse der LNW; (iii) ein Ausblick zu “Emergy analysis” und Nachhaltigkeit; und (iv) ein hypothetisch strategischer Planungsansatz für FF im peri-urbanen Bereich von Megastädten.

RESUMO

O objetivo deste trabalho é avaliar as implicações ecológicas de sistemas de uso do solo (SUS) urbanos e rurais de uma perspectiva comum focada em estoques de carbono e na mudança de uso do solo (MUS) em áreas sujeitas a urbanização em Recife - Brasil. Para analisar os espaços livres (EL) foram definidas 22 áreas experimentais que representam 6 sistemas identificados em um transecto urbano/rural; Mata natural (fragmentos), área baldia, culturas perenes, culturas anuais, áreas de recreação, e arborização de calcadas. Foi aplicada uma metodologia única em um período de 24 meses entre 2005 a 2006 composta de medições de campo e entrevistas no nível da propriedade. Foram analisados a composição estrutural, estoques de carbono, biodiversiade, indicadores de resilência (Ri) e do potencial de resfriamento. Os dados foram projetados para 6 estudos de caso que representam paisagens típicas em processo de urbanização no perímetro urbano de Recife. Foi desenhado um perfil social para apoiar a compreensão do processo de tomadas de decisão no nível da propriedade e possibilitar a criação de um cenário de MUS no qual estoques de carbono são mantidos durante o processo de urbanização sem prejudicar a funcionalidade dos EL para os seus usuários. Os resultados mostram uma grande variação entre os SUS cuja distribuição apresenta uma grande variação entre os estudos de caso. As áreas de recreação estocam aprox. a metade do carbono (24,23 t/ha) se comparadas com áreas de mata natural (48,33 t/ha) e culturas perenes (61,77 t/ha) mas apresentam o mais elevado Ri e diversidade vegetal (62 espécies). Em áreas mais populosas a função de geração de renda dos EL é reduzida, resultando em proporcionalmente mais área baldia (50% do EL) comparado com áreas de menos populosas (13,07%). Áreas de mata natural desaparecem no nível da propriedade enquanto culturas perenes tem sua importância mantida (35 e 29%) devido a sua contribuição para a subsistência da população mais pobre. Uma distribuição de 23% de área construída, 18% de mata natural, 24% de culturas perenes, 19% de culturas anuais e 16% de áreas de recreação poderia compensar os estoques de carbono reduzidos pelo processo de urbanização sem reduzir a funcionalidade dos EL para seus usuários. Finalizando, foram discutidos: (i) implicações ecológicas dos SUS; (ii) implicações da MUS; (iii) perspectivas futuras sobre analise emergetica e sustentabilidade; (iv) uma abordagem prospectiva/estratégica para o planejamento de EL em megacidades.

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ABBREVIATIONS

BA	Basal Area
BM	Biomass (Fresh)
C_f	Carbon Fixation
C_i	Crowding Intensity
CO_2	Carbon Dioxide
CP	Cooling Potential
DBH	Diameter at Breast Height
DM	Dry Mass
ECP	Cooling Potential of Evapotranspiration
EVT	Evapotranspiration
FAO	Food And Agriculture Organization
FM	Fresh Mass
GPP	Gross Primary Production
H_{eco}	Eco Height
IPCC	Intergovernmental Panel on Climate Change
ITCZ	Inter Tropical Conversion Zone
J	Joule
LUC	Land Use Change
NPP	Net Primary Production
OS	Open Space
R_i	Reslience Index
SP	Shading Potential
UA	Urban Agriculture
UNDP	United Nations Developmentprogramme
UPA	Urban And Peri-Urban Agriculture
V_{bio}	Bio Volume
V_{eco}	Eco Volume
V_{pot}	Potential Eco Volume
W_b	Wesenbergfaktor
WUE	Water Use Efficiency

1 INTRODUCTION

"The scientific communities of four international global change research programmes - the International Geosphere-Biosphere Programme (IGBP), the International Human Dimensions Programme on Global Environmental Change (IHDP), the World Climate Research Programme (WCRP) and the international biodiversity programme DIVERSITAS - recognize that, in addition to the threat of significant climate change, there is growing concern over the ever-increasing human modification of other aspects of the global environment and the consequent implications for human well-being. Basic goods and services supplied by the planetary life support system, such as food, water, clean air and an environment conducive to human health, are being affected increasingly by global change" (The Amsterdam Declaration on Global Change 2001).

While in the past global changes were attributed to a natural interference into the global system such as solar output, plate tectonics, volcanism, proliferation and abatement of life, meteorite impact, resource depletion, changes in Earth's orbit around the sun and changes in the tilt of Earth on its axis, nowadays the human induced changes gain importance (IHOPE 2010). Those are changes in the physical, biological and chemical processes that sustain life on earth as we know. Among the environmental changes resulting from human activity, some priority areas are addressed on a global scale by the United Nations Environmental Programme (UNEP) which are the climate change, environmental disasters and conflicts, ecosystem management, environmental governance, harmful substances and hazardous waste and the resource efficiency, sustainable consumption and production (UNEP 2011).

Population growth is widely accepted as one of the driving forces of global changes and green house gas emissions especially due to the increased burning of fossil fuels (Hardee 2009), increasing demand for food (FAO 2005) and the resulting land use change (Howden et al. 2007). According to the Population Division of the U.S. Census Bureau (2011) the world´s population in March 2011 reached 6.9 billion people. In the year 2007, for the first time, more than 50% of the world population lives in urban areas (UN-HABITAT 2006).

The International World Energy Outlook from the international energy agency (2008) outlines the importance of urban areas to the global carbon cycle. While cities are responsible for 71% of the carbon emissions from not renewable energy sources in 2008, this importance will increase up to 76% in the next 20 years (GCP 2010).

It is assumed that originally most urban settlements were created in productive crop areas and that the impacts caused by the rapid population growth concentrate in densely populated urban areas (Goldewijk and Beusen 2010). Approximately 25% of the world`s urban population is fed by urban and peri-urban agriculture (UPA) (FAO 2005), this means about 12% from the total population. Thus, urban areas and their surroundings can be considered as important indicators for global changes such as land use change and the resulting carbon emissions.

Table 1: Global cropland and pasture area estimates for 10.000 BC to AD 2000 (baseline, in million km2)

	Unit	10,000 BC	5000 BC	AD 1	AD 500	AD 1000	AD 1500	AD 1600	AD 1700	AD 1800	AD 1900	AD 1950	AD 2000
Cropland	Million km 2	0.000	0.048	1.31	1.24	1.53	2.32	2.55	3.00	4.19	8.50	12.14	15.32
Pasture	Million km 2	0.000	0.004	1.06	1.08	1.43	2.24	2.88	3.24	5.13	12.93	24.66	34.29
Population	Millions	2	18	188	210	295	461	554	603	989	1654	2545	6145
Cropland per capita	ha per capita	0.00	0.24	0.52	0.43	0.36	0.33	0.29	0.30	0.24	0.35	0.33	0.16
Pasture per capita	ha per capita	0.00	0.02	0.56	0.51	0.48	0.49	0.52	0.54	0.52	0.78	0.97	0.55

Source: Goldewijk and Beusen (2010)

While the definition of peri-urban areas is complex and often referred to as a place, a concept or a process (Marshall et al. 2009), there is a consensus that the social-economical, political and environmental systems in these areas are subject to rapid changes resulting from complex interactions between urban and rural systems (Tacoli 2003; Wiebel 2008). In Recife (Brazil) Wiebel (2008) could identify different problems affecting the rapid land use transformation process in the peri-urban fringe of the megacity. Those, among others, are undefined political competences, high social segregation, high informality of land tenure and security problems, unequal access to information and capacity building by rich and poor fractions of the population, increasing land prices as a result from increased infrastructure and reduction of agricultural productive land spitted and build-up in the urbanization process.

In this context of intensive transformations (population growth, rapid urbanization, high concentration of emissions, socio-economical conflicts and land use change) the resulting open spaces are reduced in urbanizing areas while the demand for their functions as carbon stocks and food production increases.

Following the logic that during the urbanization process peri-urban areas will become urban and rural areas will become peri-urban, the recognition of the advantages and disadvantages of the social, economic, political and environmental changes are crucial for a sustainable urban development (Allen et al. 1999). Already in the1970s, Odum suggested the new concept of “city open space plan” (Odum 1971). He showed that for a typical American city, the open or free space was 71% in the 1970s. If no urban planning is applied, then the free space would be reduced to 16% by the year 2000. However, with planning this value increases to 33%, increasing the importance of carbon stored in open spaces to the global climate change mitigation issues.

Yet, parallel to the functions of open spaces at mitigating global changes, including food production and carbon stocks, they fulfill very important local functions. Those are between others the supply of natural elements in the daily life of urban settlers providing recreation, relaxing and an important place for socialization (Töpfer 2006). As well open spaces acquire another typical urban function of reducing the heat island effect which is the increased air temperature of up to 5°C in urban areas (Taha et al. 1988) that results from the high absorption of solar energy from urban structures and materials (Wong 2010).

Betts (2004), from the Met Office's Hadley Centre for Climate Prediction in Exeter, Devon, says this "urban heat island" effect will intensify, and that a doubling of carbon dioxide levels in the atmosphere could triple the intensity of the heat island effect locally. In this sense, open spaces, their use and functions play a central role linking not only the transformations between the urban and the rural environments but between local and global changes as well.

2 OBJECTIVES AND HYPOTHESIS

While the urbanization process transforms locally all human systems (economy, infrastructure, social networks, security, etc.), there is no clear boundary between urban and rural areas. As a result the management of open spaces addresses transforming demands and necessities of the users and the local communities creating a huge variety of land use systems. Those range from typically rural systems like forests and agriculture to typically urban systems like recreation areas and side walk trees. The ecological implications of those land use systems and their importance to the carbon stocks and climate change issues is relativized through the regional perspective. From the urban perspective of a city planner, carbon stocks in open spaces can contribute only little to the global climate change if compared to measurements that reduce vehicle emissions while from a rural perspective they are vital and decisive.

The general objective of this research is to evaluate the ecological implications of the whole range of urban and rural land use systems from a common perspective focused on carbon stocks and land use change. Specific objectives are to evaluate and compare across the systems:

- their resilience
- their above ground biomass structure
- the biomass stocks and fluxes
- the carbon and energy stocks and fluxes
- their relative importance compared to other land use systems

The data acquired will be projected on different typical communities of the urban area of Recife and its close surroundings with the objective to understand the driving forces that define certain sets of land use systems applied to open spaces, their ecological implications and their importance as carbon stocks.

The principal questions to be addressed by this research are formulated in the following hypothesis:

Hypothesis-1: *While urban recreation areas fulfill functions as social networking, recreation, relaxing and aesthetics, they can also store at least as much carbon as urban forest fragments.*

Hypothesis-2: *Annual crops, which are often produced under informal land tenure conditions store at least as much carbon as if the land tenure is formal but kept fallow.*

Hypothesis-3: *The loss of arable land in urbanizing areas and consequently the reduction of biomass and carbon stocks on a hectare basis can be compensated by a higher crowding intensity in the land use systems applied to smaller urban backyards, meaning that the lost of biomass per unit of area is compensated by a higher biomass per unit of volume.*

Hypothesis-4: *under pressure of demographic growth the management of open spaces tends to intensify while the available area is reduced, resulting in relatively less fallow land if compared to less densely populated areas.*

3 GENERAL FRAMEWORK

3.1 Introduction to climate change issues

Climate change is a polemic issue when it comes to discuss the responsibility of the society, the economy and the development of new technologies and energy sources (UNEP 2011). While a huge part of the scientific community assumes the global changes caused by manmade activities the principal reason for global changes that affect the climate (UNEP 2009), others question this theories (Kobashi et al. 2010). The intergovernmental panel on climate change (IPCC) was established by the United Nations Environment Program (UNEP) and the World Meteorological Organization (WMO) to feed the international community with scientific data about climate change, its causes and impacts on the environment and on the socio-economic systems. The idea of the temperature increase in the atmosphere caused principally by human activities is based on the assumption that green house gases reflect the radiation coming from the earth surface back to the earth surface thus hindering this energy of radiate back to space and increasing the atmospheres temperature (Mc. Mullen 2009). Yet, other scientists like Ermecke (2009) state that this assumption is false and in reality the increased concentration of carbon and other elements in the atmosphere increases the conduction of heat out to space, thus creating a cooling effect besides hindering as well a part of the direct radiation coming from space to earth.

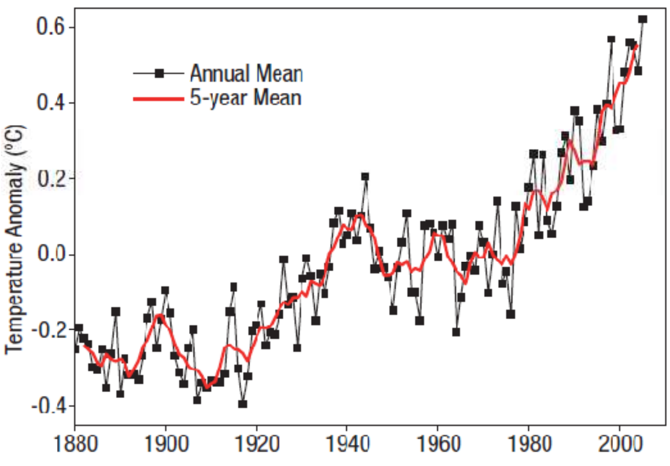


Figure 1: Surface temperature anomalies relative to 1951 - 1980 from surface air measurements. Source: Hansen 2006.

While the scientific community seems to be partly spitted around the reasons for climate change, the fact that climate change is happening is broadly accepted (Figure 1). The possible scenarios of ice melting in Polar Regions rise of the sea levels and extreme weather events range from catastrophic consequences to life on earth as we know (Maslanik et al.

2007; Tarnocai et al. 2009; Vaughan et al. 2009; Wang 2009) (Figure 2) to more optimistic scenarios in which nature reacts and balances climate change. Yamano (2011) analyzed coral reefs in Japan and measured an increase of 14 km/year with increasing seawater temperatures and Brown et al. (2010) simulated a primary production increase around Australia, benefitting fisheries catch and increased biomass of threatened species, feeding 12 different models with the IPCC emission scenarios.

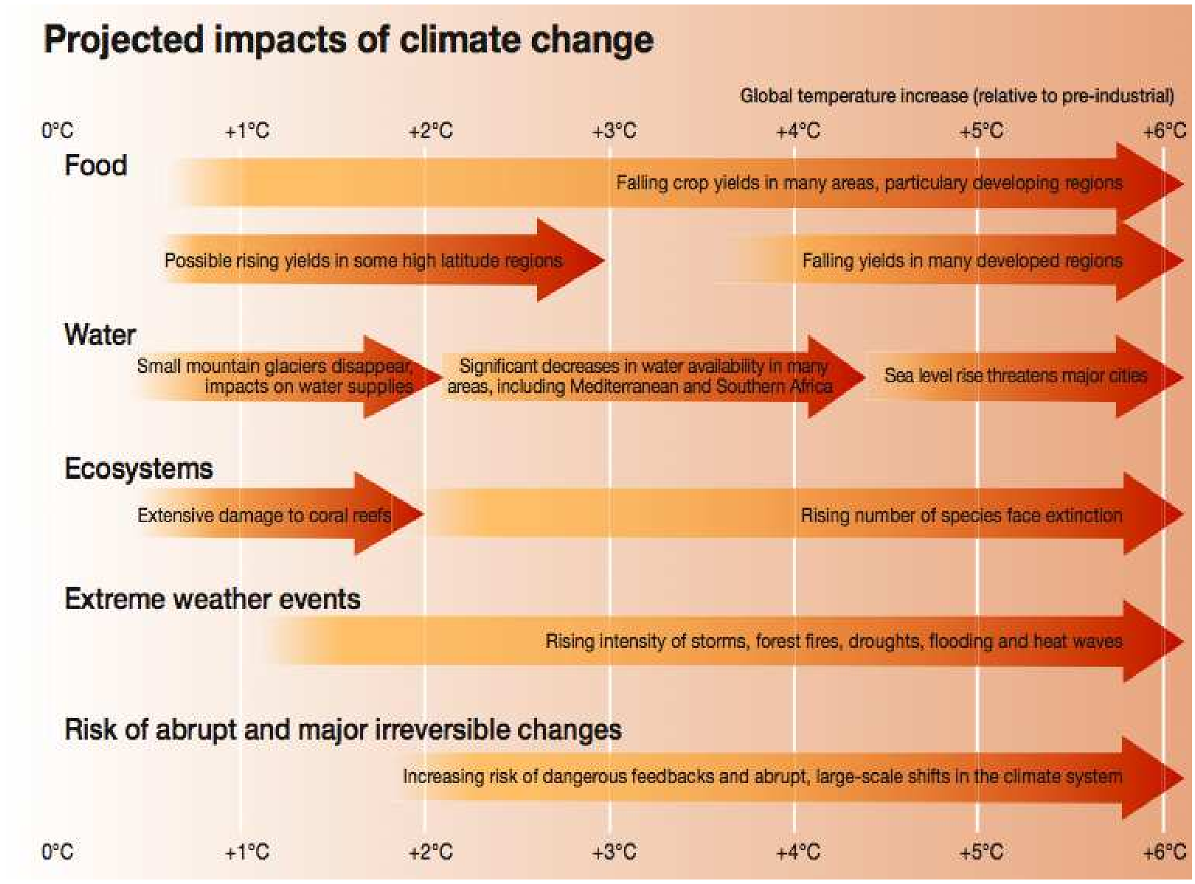


Figure 2: Projected impacts of climate change. Source: Stern Review 2008.

React to such changes by investing huge amounts of energy and financial resources into research and development of new technologies, land use techniques, revised industrial standards and even re-designing socio-cultural paradigms is an obligatory mission of this and the oncoming generations (Ramanathan 2008). According to Craven (2009), the issue of climate change and global changes is not a matter of speculating if the reasons are manmade or not, but how to behave now to ensure the lowest losses in the future. Not reacting to such changes creates a risk that is proportionally a lot higher than investing these huge resources now even if the changes are driven by nature like increased solar radiation that is not manmade and even if these changes can be balanced by responses from the environment.

Basically there are two strategies being addressed by policy makers and scientists to react to climate change: mitigation and adaptation (Locatelli et al. 2010). Both are subject to synergies and trade-offs that have to be understood and managed. While mitigation projects focus on the reasons for global climate change like maintaining and increasing carbon stocks in forests, adaptation projects address the importance of environmental services provided by ecosystems that help to reduce the risks for the society in a local scale such as storm flow regulation, erosion control and the role of forests for the protection of water resources in urban areas (Turner et al. 2009). In order to improve the synergies and reduce trade-offs between these two strategies it is important to understand their relationships and interactions with development plans and institutions (Klein et al. 2005).

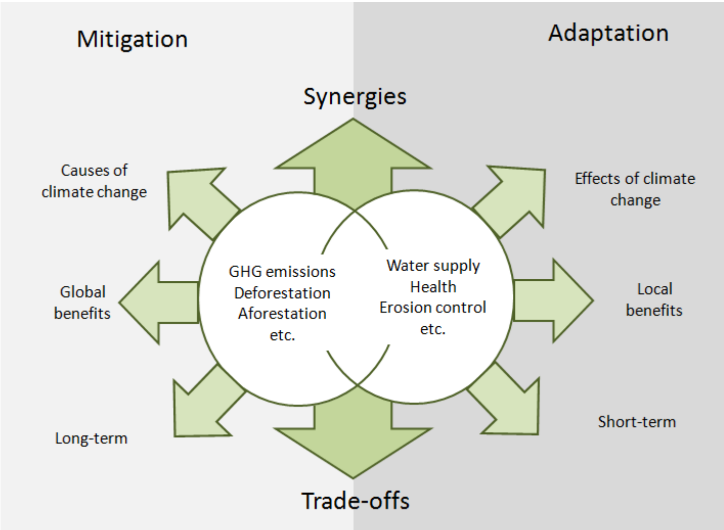


Figure 3: Synergies and trade-offs in climate change issues. Source: Created based on CIFOR (2010).

3.2 Carbon stocks and land use change

The global carbon cycle is one of key research issues in the studies of climate change and regional sustainable development as well as one of main subjects for international coordinated research programs on global change (SINO 2005). Carbon in the form of carbon dioxide (CO_2) is the most common GHG (green house gas) since the industrial revolution led to the burning of immense amounts of coal, fire wood, fossil fuels and also the land use change caused mainly by the industrialization of agriculture. While the emissions of carbon dioxide vary along the year due to the change in natural atmospheric conditions (temperature, water vapor etc.), there is a consensus between the scientists (Keeling 2005) that the overall trend in CO_2 in the atmosphere is going up, about from 320 ppm in the sixties to almost 390 ppm in 2010 (Figure 4).

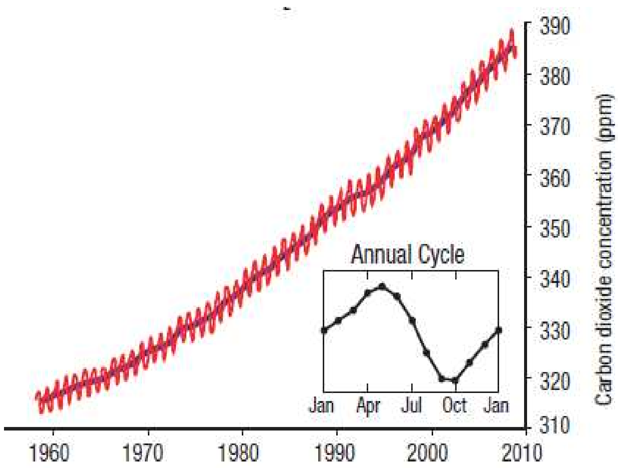


Figure 4: Increase of carbon dioxide in the atmosphere from 1960 to 2010. Source: Keeling et al. 2005.

Even if current efforts in ecosystem management to mitigate the climate change have a focus on carbon sequestration, it is important to understand, that to succeed, those efforts have to consider the interaction between ecosystem and the socio-economic system, thus, with the goal to result in a variety of ecological and societal benefits. In the mean while, the role of carbon itself to the global climate change does only partially address the issues of ecosystem-climate interaction (Chapin et al. 2008).

Terrestrial ecosystems absorb about 30% of all anthropogenic carbon emitted to the atmosphere by fossil fuel burning and deforestation. Forests are the most important carbon pools in terrestrial ecosystems which covering almost one third of the terrestrial surface of the earth (Figure 5), they hold more than twice the amount of carbon than the atmosphere itself (IPCC 2007). The deforestation of tropical forests accounts for almost 17 % of all GHG emissions what makes the land use change a central issue of the global carbon cycle.

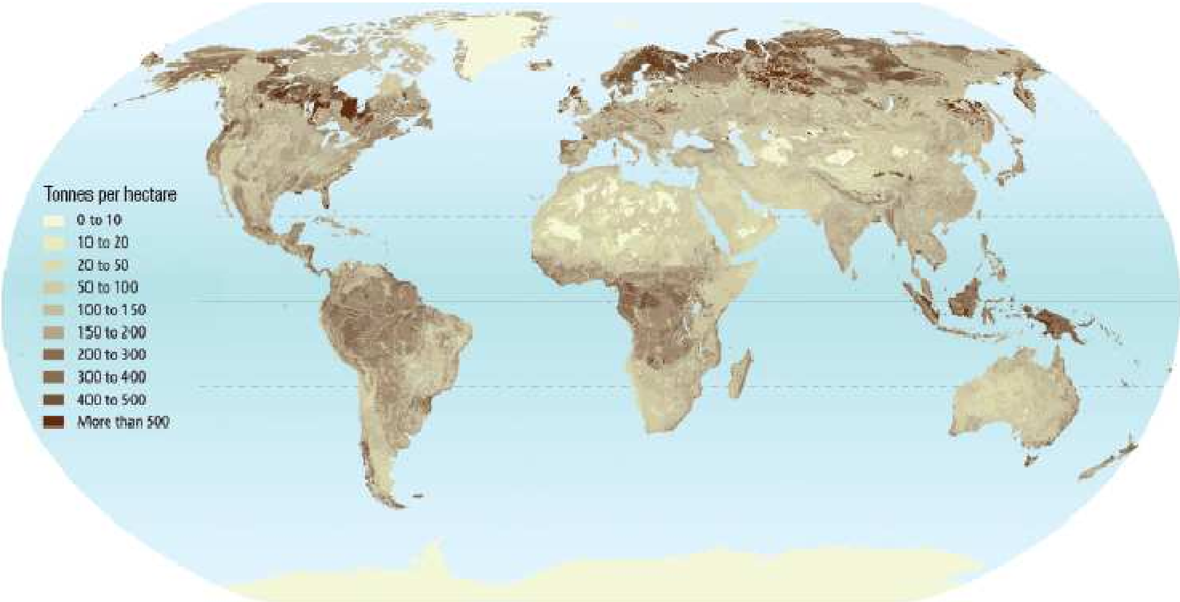


Figure 5: Carbon storage in living organisms, litter and soil organic matter. Source: Trumper et al. 2009.

While the expansion of agriculture is the principal reason for carbon emissions from deforestation (Figure 6), agriculture is also one of the most susceptible socio-economic activities to climate changes (Howden et al. 2007). Yet, there are many forces that drive decision making in agricultural activities, specially the demand for food from the increasing world population. Thus, agriculture is the activity that is constantly balancing between the demand of the society for food, energy, clothing and water, and the direct interest of the farmer to manage his natural and financial resources in a way to sustain his activity on a long term basis. Summing up, population growth and economic development are the major forces that push land use change, having a greater impact in regions where farmers have less access to information and resources. External inputs such as capacity building and the introduction of appropriate technologies can reduce the risks of land use change and enhance the potential of agricultural systems to store carbon besides other positive effects on the water cycle and on biodiversity (Trumper et al. 2009).

One classical example of land use change is the oil palm plantations (*Elaeis guineesis*) that already represent 10% of the world's permanent crop area (Dewi et al. 2009). Feintrenie and Levang (2010) assessed the impact of the oil palm development in Indonesia, the world´s leading producer, on the economic wellbeing of farmers and concluded that many smallholders "…*have benefited substantially from the higher returns to land and labour afforded by oil palm…*" compared to the alternative of managing clonal rubber (*Hevea brasiliensis*), rubber agroforest systems and inundated rice systems (*Oryza* ssp.). Yet, with carbon stocks of less than 40 t/ha, the actual conversion from forests to oil palm plantations results in an increased emission of carbon to the atmosphere that would take decades to centuries to be offset by the replacement of fossil fuels by palm oil. Since the plantation is replanted after 25 years, a carbon stock increase is only possible if plantations are set in former grassland and abandoned non forest land with lower carbon stocks than 40 t/ha. (Dewi et al. 2009).

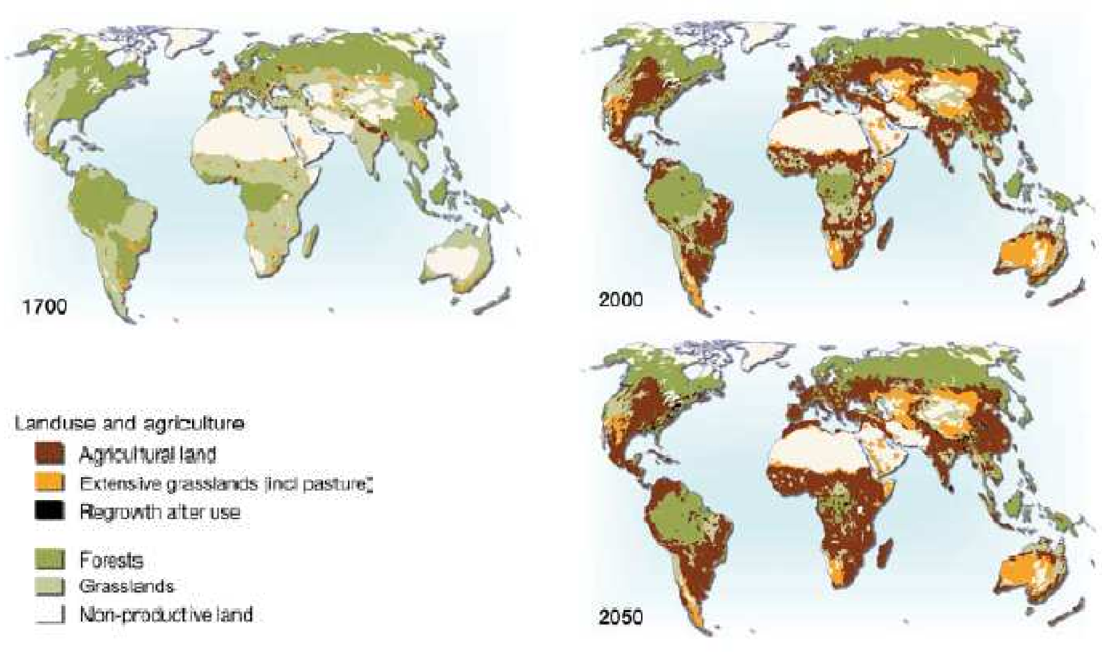


Figure 6: Projected land use changes, 1700 - 2050. Source: Nellmann et al. 2009.

Agricultural systems also offer an opportunity for reduced carbon emissions and increased stocks through land use change, especially with an appropriate method of valuing carbon in CO_2 equivalent, forestry and agriculture combined could become more important than any other single sector (IPCC 2007). Yet, even with no valuing of the carbon stocks in CO_2 equivalent, there are examples of land use change in the agricultural sector that have positive implications on the global carbon cycle.

Driven by better prices for ecological vegetables, farmers in Teresopolis (SE-Brazil) preserve forest fragments to ensure their water supply (Torrico 2006). Others in Mexico are converting coffee plantations (*Coffea arabica*) under shade trees (*Inga* spp.) into systems where high quality organic certified coffee beans are produced (Pohlan 2006) under the shade of valuable tropical timber trees (*Acrocarpus fraxinifolius*, *Cedrela odorata*, *Colubrina arborescens*, *Cordia alliodora*, *Melia azederach*, *Ocotea* spp., *Swietenia macrophylla*, *Tabebuia donnell smithii*, *Tabebuia rosea*, *Tectona grandis*), increasing the carbon stocks from 15 to 72.8 t/ha after a 12 year conversion process (Jende 2005). It is estimated that generally agroforestry systems in humid regions can store 50 tons of carbon/ha while having a positive impact on the local biodiversity (Montagnini and Nair 2004).

The approaches that aim reducing the impact of land use change to the global carbon cycle do not only address changes from forest to agriculture, but also from conventional agriculture to more productive, forest like and diverse systems which in turn can provide higher economical, social and ecological benefits, stabilizing the productive unit (Pohlan 2005).

3.3 The urbanization process and its socio economical implications

The urbanization process worldwide is increasing rapidly, mostly in terms of demographic growth. It is expected that 20% of the urbanization that will happen in the next 20 years, will occur in developing countries. Also the largest megacities will be found in the developing world. Generally it is possible to assume that the less urbanized parts of the world will hold the highest urbanization rates, for example in sub-Saharan African countries an urbanization of 4.58% p.a. is to be expected, the highest in the world (UN-HABITAT 2006).

The fast increase of urban areas in the developing world started with the industrial revolution in the sixties. Attractive job opportunities in the cities and industries that were mostly situated in urban areas triggered a migration process from rural areas that at that time were facing a reduction of socio-economic opportunities for the settlers (Coy 2003). Nowadays, the natural population increase is more and more the reason for the fast rates in which urban areas expand (Mertins 2006). By instance, differently from the developed world, in developing countries the migration process from rural to urban areas surpassed the velocity of industrialization (Hoffmann 1995) what lead to a “hyper-urbanization”. As a result, the opportunities expected by the migrants in the urban areas are affordable only for a part of the urban population what creates a segregation of urban landscapes with strong contrasts between rich and poor areas (Töpfer 2007).

Originally urban settlements were created on the most productive crop lands (Goledwijk and Beusen 2010). Build-up areas are estimated (year 2000) to cover about 3 to 5% of the total cropland surface (Potere and Schneider 2007) and projections based on a medium population growth (UN 2008) estimate an increase up to 7% in the year 2050 (Stehfest et al. 2009). The human development report from the UNDP (1996) estimated that urban and peri-urban agriculture (UPA) is responsible for 15 to 20% of the world`s food production, what indicates the relevance of those areas for the socio economical development of the urbanization process.

Many authors (Adell 1999; Allen 1999; Tacoli 2003) state that several problematic processes like increasing social inequalities environmental degradation and the resulting land use change (LUC) are the result of the complex combination or interaction of rural and urban aspects of the problems. Thus, occurring more acutely in the peri-urban areas than elsewhere and affecting especially the poor. The definition of peri-urban is very complex, sometimes being defined as a place when referring to the geographic edge of a city, as a concept when referring to the interface between urban and rural activities, institutions and perspectives and last but not least as a process when referring to the movement of goods and services between urban and rural areas (Marshall et al. 2009).

Wiebel (2008) analyzed the peri-urban fringe of Recife and found a high degree of informality regarding land tenure, lacks in infrastructure, services and information in all levels such as market, regulatory constrains and technical assistance. She concluded that during the urbanization process and the increase of land prices less lucrative activities and land uses are replaced by more profitable alternatives for the land owners, often at the cost of displacing poor families to other less attractive regions. With less financial possibilities and know how these population is forced to invade new areas, being an integral part of the uncontrolled urbanization process. Conflicting interests between rich and poor, land owners and informal users under weak political and institutional circumstances define the diversified peri-urban landscape of Recife. Urban and peri-urban agriculture generally is an important income source for the population but if productivity is low, urban jobs are pursued by the new generations, while efficient and productive areas are even creating employment for urban settlers. The less densely populated and nature oriented areas are valued subjectively by rich and poor, both considering the closeness to nature, safety, and other advantages of living in the peri urban fringe, indicating at least a potential of protecting the strength of these areas through the integration of the local stakeholders into the urban planning process.

3.4 The urbanization process and its ecological implications

The Brundtland World Commission on Environment and Development (1987) identified a number of serious environmental problems caused by rapid urban growth. Modern cities and their suburbs endure more contaminated atmosphere and water-body systems, less sunshine, and different microclimates from non-urbanized territories (the so-called "urban heat island effect"). An analysis by the UK Met Office shows that the effects of global warming will be much more intense in urban areas. Among many impacts that the urban areas of the developing world generate on socio-economic and cultural systems like the intensified social segregation, scarcity of job opportunities, expansion of informal activities and informal land occupation (Coy 2003), this research will focus on the ecological implications. Besides the intensified emissions mentioned above, the biodiversity is reduced by the disappearance of vegetated areas and the increase of sealed areas. Schmidt (2007) could analyze different open spaces in the urban areas of Recife (Brazil) and concluded that while fallow land areas and urban forest fragments are still dominated by up to 76% native plant species, the typical planed urban open spaces like parks, side walk trees and private home gardens were dominated by up to 73% exotic plant species. Even though, the absolute diversity in these urban areas, which are planned to fulfill urban functions (recreation, esthetics, shading), is higher.

In Recife, the planning of the urbanization process considered open spaces until the twenties, because of the valorization of the neighborhoods. After the twenties, the planning of open spaces was almost neglected, what led to diverse ecological problems: Transformation of fragile ecosystems like mangroves and forests; occupation of riparian areas, where inundations are frequent; occupation of hilly areas, specially by the poor; substitution of single family households by big luxurious buildings, what increases the demand for infrastructure; solid waste disposed in water bodies, reducing water quality for consumption; increase of vehicle traffic and the emission of pollutants and green house gases. Public green areas in Recife account for only 480 ha (2.17%) and if green areas besides streets are considered, they increase 450 ha making a total of 930 ha (4.2%) of public green areas in Recife (PLANO DIRETOR RECIFE 2005), out of which a large part has turned to degraded and insecure no-man's land.

3.5 The role of urban open spaces in climate change and urban development issues

The "International Association for Urban Climatology (IAUC)", supported by the "World Meteorological Organization (WMO)", keeps a bimonthly newsletter were most of the worldwide research projects on urban climate and their results are published. Studies on urban climatology are mostly focused on the issues of greater impact from the perspective of urban planning like the concentrated emissions in transport systems (Carslaw 2004; Leuzzi et al. 2010), the air flows (Barlow 2004; Candido et al. 2010) and their effect on the dispersion of pollutants (Britter 2003; Suppan 2010) and the contribution of build up areas to the heat fluxes in the urban environment (Dupont 2004; Kim 2010).

From a list of 559 articles and papers (Salmond 2005) published between the years 2000 and 2004 on urban climate, only 15 presented a direct or indirect reference to the role of open spaces in the (local) urban climate. At only 10 of those references (not even 2% of the total) the urban vegetation plays a central role in the research context. While the shading effect of tall buildings (the so called "street canyons") is highly estimated, the citations on urban vegetation focus mostly on their contribution to the human comfort and on the effect of the "heat island" and on the phenological development of trees compared to rural areas (White 2002). In a list of 721 bibliographic references from 2005 to 2010 published by the WMO none refers to carbon stocks from open spaces in urban areas in a global climate change context.

Climate change issues in rapidly urbanizing areas especially in the developing world address primarily adaptation strategies rather that mitigation strategies because the impacts of climate change on the urban systems might be disproportionally higher than the contribution to climate change from cities in most cases (UN-HABITAT 2010).

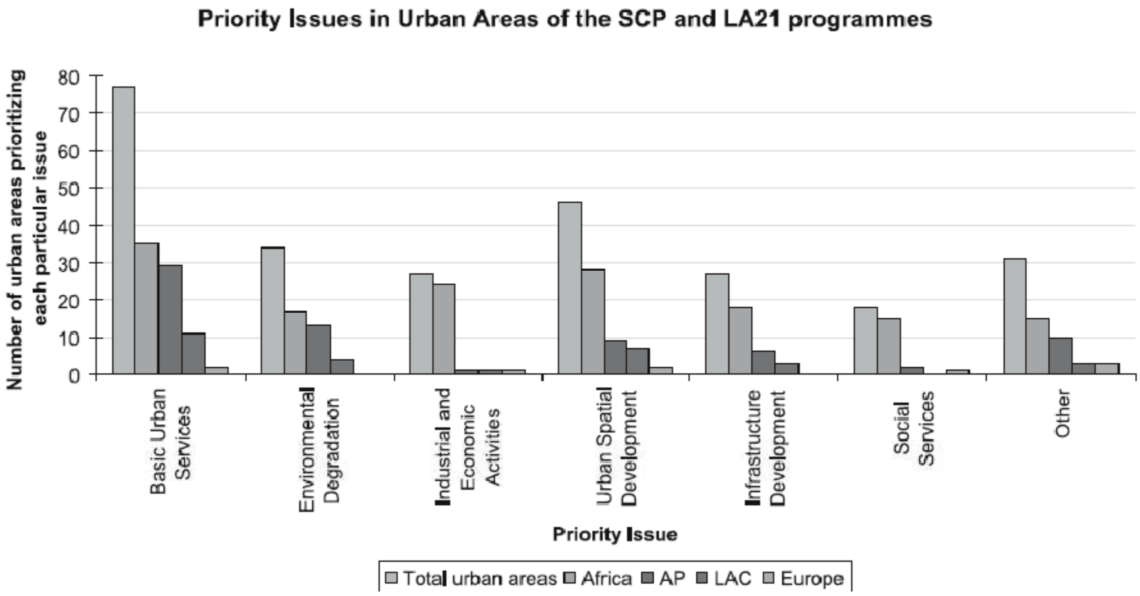


Figure 7: Priority issues in urbanizing areas. Source: UN-HABITAT 2009.

Focusing on a sustainable urban development the UN-HABITAT (former United Nations Centre for Human Settlements) created the "Sustainable Cities Programme (SCP)" and the "Localizing Agenda 21" to find solutions for ongoing ecological problems in urbanizing areas. Figure 7 shows which issues are priorized by governments pursuing a sustainable urbanization process (UN-HABITAT 2009). It is clear that most of the of the cities face deficits in very basic needs such as public services, infrastructure, urban spacial development including land tenure regulations, water supply, energy supply, poverty alleviation and social inclusion (UN-HABITAT 2010).

Hayek et al. (2010) emphasizes that the planning of urban open spaces need to focus not only on the socio-economical but on the ecological implications as well. She mentions that one single variable of importance for architects and planners like the cooling effect of vegetation can have other positive effects like the economy of water resources, but other ecological aspects known from ecosystem analysis should be integrated.

3.6 The importance of open spaces to the local urban climate

One important research issue that fills the gap between the importance of large vegetated areas that mitigate climate change through carbon stocks and the importance of fragmented urban open spaces is their importance for the reduction of the heat island effect caused by urban structures. The evaporative cooling effect from urban vegetation occurs when warm dry air gets in touch with water molecules, they turn to vapor because the temperature and the water pressure of both tend to equalize. This physical, chemical and biological process consumes energy from the warm air that gets cooler (Robitu et al. 2005).

The heat island effect (Figure 8) can increase the air temperature in cities up to 5°C compared to rural areas around the city (Taha et al. 1988). This discomfort is compensated by the use of air conditioners that consume electricity generated by fossil fuels (Consumer Energy Center 2011). Simulations in Sacramento (USA) show that the energy consumption for cooling purposes can be reduced between 21 and 43% by the increase of vegetated areas and the water surface (Haider 2003).

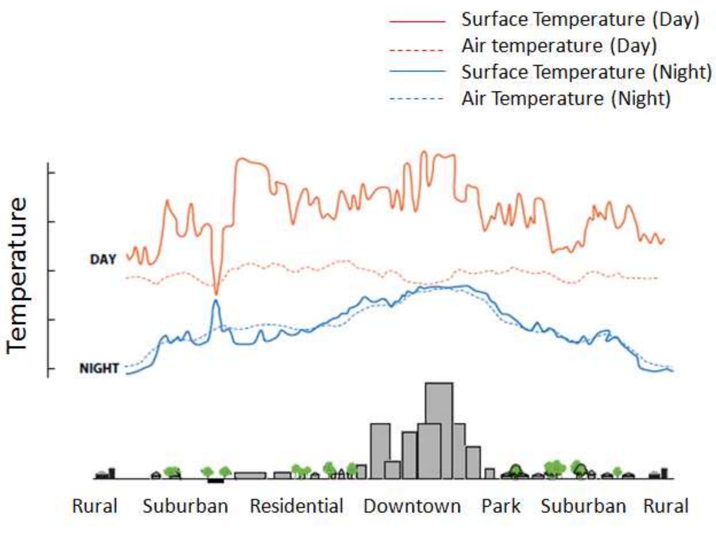


Figure 8: The heat island effect. Source: Adapted from Wong 2011.

Another simulation shows that if the Amazon tropical forest would be completely transformed into grassland, the principal effect on surface temperatures would be caused by the reduction of the evaporative cooling effect from the tree canopies, thus increasing the surface temperature between 3 and 5° C (Dickinson et al. 1988).

The cooling effect from vegetation is well known. Plants can absorb between 60 and 90% of the incoming solar radiation (Elsa 2011), partitioned into direct and diffuse shortwave radiation from the sun and long wave radiation eradiated from objects in their surroundings. Stanhill (1970) could correlate a reducing albedo (increased abortion) to an increasing vegetation height. According to the values from Moneo (2010) this would mean that the natural forest, perennial crops, recreation areas and the street tree systems reflect between 10 and 15% of the incoming solar radiation while fallow land and annual crops systems reflect between 12 and 30% back to space in short waves. Further, plants eradiate about 72% of the gross absorbed radiation in log wave bands back to the atmosphere. About 96% from the net radiation absorbed is dissipated to the atmosphere through evapotranspiration (57% from the net radiation) and convection (39%). The left 4% is dissipated by photosynthesis (stored in biomass), warming of the canopy and conductance of heat to the soil (Tollenaar 2008).

Evapotranspiration is the process in which water evaporates from leaves through the stomata. At normal atmospheric pressure the specific latent heat of water evaporation is 2270 kJ/kg (The Engineering Toolbox), this is the energy "consumed" by the process and results in cooling. The amount of water transpired by plants is related to the carbon fixed in its biomass, depending on the water use efficiency that varies between species at similar atmospheric conditions (Cernusak 2007; Tan 2010).

Materials such as concrete and asphalt have a low albedo, this means that they absorb about 90 and 95% of the incoming radiation and radiate this energy back to the atmosphere as long wave radiation and sensible heat warming the air and objects in their surroundings. In urban areas this radiation contributes to the heat island effect. The shade created by the interception of the solar radiation by trees can reduce the radiation on concrete and asphalt down to 17% from the total radiation (Choi 2006) reducing the heat island effect.

Some interesting approaches try to conciliate vegetation and urban structures on the same area rather than side by side competing for space, making use of the isolating properties of vegetation. One example are the roof top gardens that can reduce up to 50% the heat flux into the rooms under them through isolation (Onmura 2001) and create a cooling effect through evaporative cooling (Koerich 2010) at once. Roof top gardens reduce the horizontal competition between build up and "open" areas by reallocating both vertically. Roof top gardens are wide spread in European and North American countries (Koerich 2010), especially the extensive systems which are characterized by the use of small ground cover plants grown on a shallow substrate and in lightweight systems which require a low level of maintenance (Köhler et al. 2005).

Yet, even in humid tropical conditions they have to deal with periods of drought stress what results in a limited diversity of suitable plant species (Tan 2009) and the need to design appropriate substrates, unless an extra investment in effective irrigation systems is done (Williams et al. 2010).

3.7 The importance of open spaces to the global carbon cycle

This research treats the climate change from the perspective on the potential of "open" and unsealed rural land to store carbon that is reduced and changed by the urbanization process. The ecological implications of urban not natural structures and systems (emissions, buildings, street lay-out) are neglected. Only the vegetated urban systems are considered, to make a parallel between urban and rural land uses possible.

Keeping this focus it is broadly accepted that trees in urban open spaces are important sinks for atmospheric carbon i.e. carbon dioxide, since 50% of their standing biomass is carbon itself (Ravindranath et al. 1997; Penman et al. 2003). Yet, even with the Importance of forested areas in carbon sequestration already accepted and well documented (FSI 1988; Tiwari and SINGH 1987), hardly any attempts have been made to study the potential in carbon sequestration from urban open spaces (Patwardan and Warran 2005). Studies on this topic often have to use adapted methodologies and assumptions that originate from forestry research (Stoffberg 2010).

Jenkins (1999) compared carbon stocks and fluxes in forested and non forested areas, and concluded that non forested areas (including open spaces and agricultural land in intra and peri-urban areas) could add substantially to current estimates of local, regional and national carbon balances, which are currently based on forest land only. Stoffberg (2010) estimated that the street trees in the south African city of Tshwane have a potential of storing up to 54.630 tons of carbon in the year 2032 on an area of 1644 km² (164.400 ha). This value is very low on a hectare basis, but the author considered only the street trees and does not refer to other urban open spaces.

Moreover, in most studies of the global carbon balance, which serve as a basement for the calibration of the GCC models, the role of urban areas is omitted. While the ecological potential of natural systems is reduced by the loss of area caused by the urbanization process, Hopkins (2005) argues that in urban territories, organic carbon should be divided into four main groups: Biomass in humans and animals; biomass in trees and other plants; carbon in construction material, furniture, books; carbon in solid waste, thus compensating partially the reduction of carbon stored in open spaces.

3.8 General aspects of urban agriculture as an alternative for open space management

Urban agriculture is defined as "the practice of cultivating, processing and distributing food in, or around (peri-urban), a village, town or city" (Bailkey 2000). Yet, not the urban location of the agricultural activity differs urban from rural agriculture, but its interaction with urban economic and ecologic system (Zeeuw 2004), thus, dealing with:

- the use of urban residents as laborers
- the use of typical urban resources (like organic waste and urban water for irrigation)
- direct links with urban consumers
- direct impacts on urban ecology (positive and negative)
- being part o f the urban food system
- competing for land with other urban functions
- being influenced by urban policies and plans

Over the last decade an increasing number of national governments and city authorities, supported by international development agencies (including IDRC, FAO, UNCHS, UNDP, CIRAD, NRI, CGIAR, GTZ, ETC and others) have started to integrate urban agriculture into their policies and programs, recognizing the importance of (intra- and peri-) urban agriculture for solving persistent urban problems, such as increasing urban poverty and food insecurity, increasing problems with the disposal of urban wastes and wastewater, the growing ecological footprint of the city and the lack of green spaces in the urban environment (RUAF 2009).

Studies on urban agriculture are abundant and refer to available market structures, infrastructure for the agricultural activities, proximity to retail markets, access to resources, access to land, access to labor and competition with other urban activities (Allen 2001; Bendavid-Val 1989; Zeeuw 2004; Mlozi 1992; Rabinovitch 2001; Rivera 2001). Also the importance of urban agriculture in the organic waste and water cycle of urban areas is emphasized for a long time (Dulac 2005; WHO 1989).

The available literature on urban agriculture is contradictory in its conclusions. Some sources indicate that urban farmers are highly dynamic and innovative (hydroponics, warehouses, drip irrigation, rooftop farming, reuse of organic wastes and waste water, niche products) due to its closeness to markets and urban consumers, better possibilities for contacts with exporters (flowers, herbs, mushrooms, etc.) and closeness to suppliers of inputs. Some of the urban farmers are farmers by choice who try out new products and techniques not hindered by the traditions in rural farming.

Urban farmers also have the advantage that the head offices of most extension organizations and research institutes are in the cities and interaction with them is easier as soon as access has been obtained. Others (e.g. Streiffeler 1991) come to the conclusion that urban cultivators are hardly interested in trying new things. Factors that may explain this behavior include the poverty of a substantial number of the urban producers, insecurity of land use, lack of extension services for urban farmers and limited technology development for urban agriculture. According to Zeeuf (2005), this two coexist in the same city.

Fact is that the urban poor are the most affected by global changes such as climate change (Commission on Climate Change and Development 2009), rising food prices (FAO 2009), growing scarcity of fresh water and increased streams of solid wastes (World Bank 2000; UNESCO 2003). That why urban agriculture is getting an increased importance in strategic climate change issues and international institutions like the "World Meteorological Organization" and the "Rockefeller Foundation". These institutions are suggesting and recommending governments to include urban agriculture in their strategic plans and policies (Rumbaitis 2009).

While most of the local and regional development plans address the issue of urban agriculture with restrictions and prohibitive measurements (due to the high degree of informality), others are including the type of use of open spaces into their master plans to create more resilient cities. Examples are Bogota (Colombia), Dakar (Senegal), Pretoria (South Africa) and Beijing (China) (RUAF 2009).

In practice this means to recognize agriculture as a permanent form of land (open space) use, incentive the production of local food and income generation, create clear policies to optimize the effects of buffer zones, reduced erosion risks, improved decentralized water and waste cycles and other multiple functions of urban agriculture (RUAF 2009) that other land uses can only partially address inside a city.

4 MATERIALS AND METHODS

4.1 General description of Recife

Recife is located at 8° 04' 03'' S and 34° 55' 00'' W and was the first Brazilian capital when it was founded in the year 1537. Recife is located at the Atlantic Ocean with a total area of 218 km² and a population of 1.53 million people in the city and 3.7 millions in the metropolitan area. Surrounded by rivers and crossed by bridges, Recife is full of islands and mangroves that magnify its geography. It is known as the Brazilian Venice, thanks to its fluvial resemblance with the European city, and is considered one of Brazil's cultural capitals. The climate is considered warm and humid with an average temperature of 25.2°C. The relief is composed of 67.43% hilly areas, 23.26% flat areas, 9.31% aquatic areas or wetlands and 5.58% of environmentally important and protected areas with some constrains despite construction (ZEPA, zona especial de protecao ambiental). Recife is sub-divided into 6 administrative units and in which are identified 66 areas of special social interest (ZEIS) for development purposes.

A very particular characteristic of Recife is that the city was constructed on different islands and is called the “Brazilian Veneza”. Surrounded by mangroves and rivers Recife is a city with strong social contrasts, considering the existence of 490 favelas.

Historically the sugar export to Europe pushed the economy but nowadays 95% from the GDP is generated by services and trade activities (Prefeitura do Recife 2006).

4.2 Physic natural and climatic description of the Study area

4.2.1 Geography

Recife is located in northeast Brazil and 35° W at the extreme eastern coast of the South American continent and 8° south of the equator. The city spreads over a low-land area with 50 Km² from the Atlantic Ocean to the elevations located at the western fringe (Figure 9). A huge net of rivers and water resources flow through this low-lands creating Islands and flooded areas. The most important rivers are the Capibaribe and the Beberibe (Castro 1948).

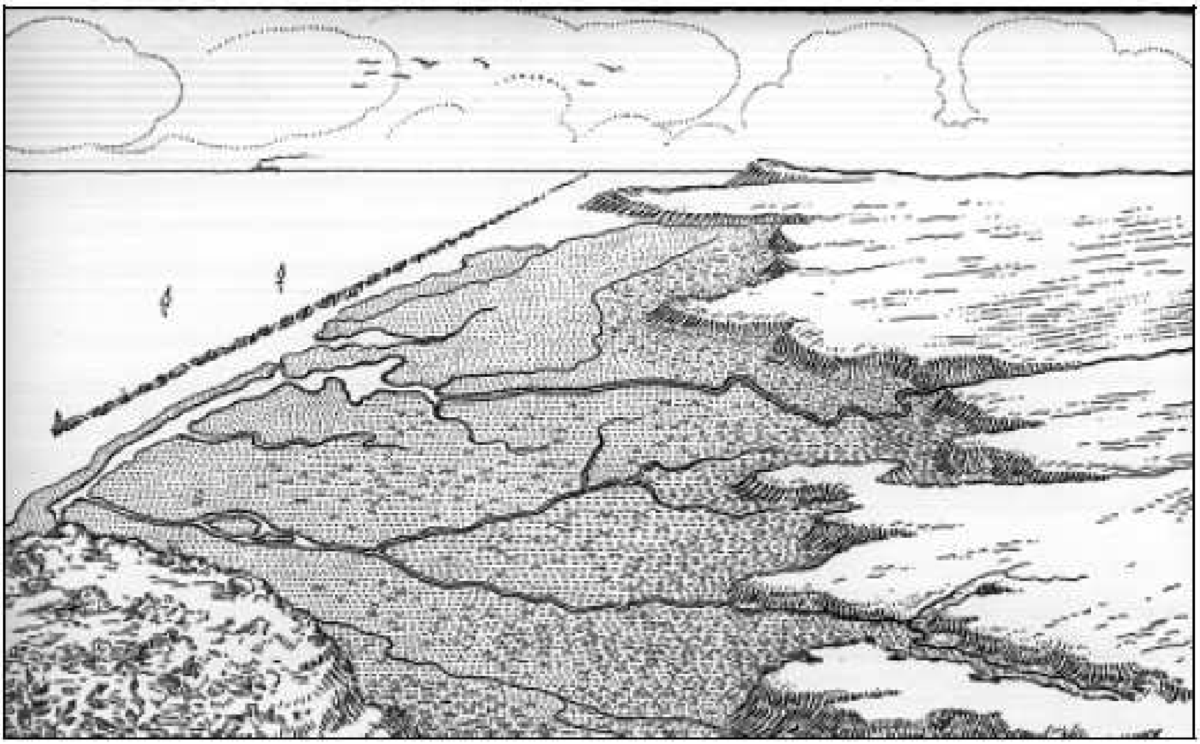


Figure 9: Illustration showing the lowlands where Recife is located, the limiting hills on the west and reefs in the east. View from north to south. Source: Castro 1948.

4.2.2 Atmosphere

Brazilian territory has a total Area of 8514876.599 km² according to the IBGE (Brazilian geography and statistical institute). The largest part of this territory is located between the equator and the southern tropical belt, what means that the tropical energy constrains control the large scale atmospheric circulation resulting in a small potential energy reservoir and large sensible and latent heat stocks.

The northern part of Brazil is principally influenced by the trade winds which originate on this huge surface and are known as very stable wind systems. Recife is strongly influenced by the intertropical convergence zone which creates a line of cloudiness that defines the earth thermal equator and separates the north and south tropical circulation systems (Haltinger 1980) (Figure 10).

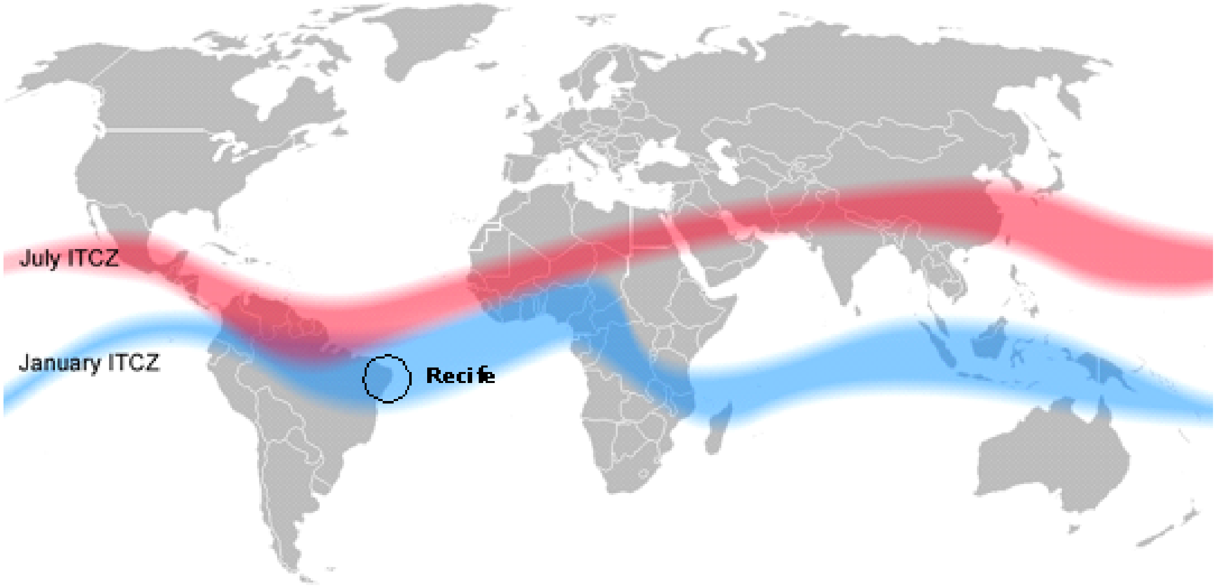


Figure 10: Intertropical conversion zone (ITCZ). Source: Halldin 2006.

Orography is rather influenced by the large scale circulation than by relevant mountain chains. Land cover indeed has a more significant role, for example the atmospheric boundary layer formed between the Amazon basin and the dry inner lands in the northeast.

In Recife, the winds blowing from the ocean bring in a high relative humidity throughout the year. The mean temperatures in January, the warmest month, range from 25°C to 34°C. January also has a low rainfall incidence with 53mm of mean incidence. The coolest month is July with means between 22°C and 31°C and high precipitation with means of 254 cm of rain (Figure 11) (BBC Weather).

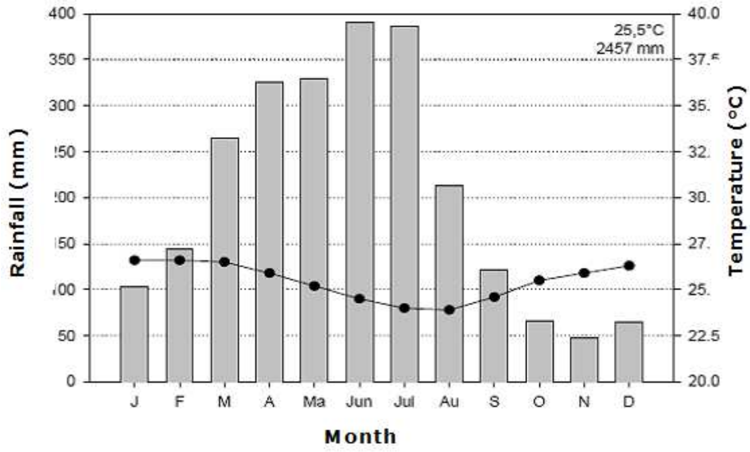


Figure 11: Climate chart of Recife. Source: EMBRABA 2007.

4.2.3 Vegetation

The Atlantic rainforest is dense evergreen vegetation (Floresta ombrofila densa) which originally stretched from the southern parts of Brazil, Argentina and Paraguay up to the northeastern Brazil where Recife is located. Around the sixteenth century the Mata Atlantica covered an area of 1.5 Million km². With the beginning of exploitation of Wood products and agriculture especially sugar cane by the colony this ecosystem was progressively reduced. In Recife the Forest was transformed in sugar cane, coffee and cocoa plantations. Afterwards an intensive urbanization process started depleting the last natural resources at Brazilian coastal areas for the construction of buildings, roads and other urban structures (Leitão Filho 1994).

Today the remaining area covered by the Atlantic rainforest corresponds about 5 to 6 percent of the original area which was a strip with 150 km wide and 3000 Km along the coastal region (Machado et al. 1998; Ranta et al. 1998). The Atlantic rainforest is natural habitat of about 53.5 percent of endemic species and is considered one of the most important hotspots in the world (Myers et al. 2000).

According to Andrade and Rodal (2004) the most important plant families in the northern part of the Atlantic rainforest are the Fabaceae, Rubiaceae, Bignoniaceae, Lecythidaceae and Moraceae. Also a high variety of epiphytes is found specially represented by the Bromeliaceae, Gesneriaceae, Piperaceae, Orchidaceae, Araceae, Heliconiaceae und Pteridophyta.

Due to the geographical conditions specially in Recife with low-lands many times flooded by the ocean and rivers, a large part of the city was originally and some parts up to now covered by a mangrove vegetation which is represented by some urban fragments, creating a very particular urban eco-system not found in other mega cities.

4.3 Experimental areas

To analyze the different ecological parameters of open spaces 22 representative experimental areas were defined. Each of them belongs to one type of typical land-use-system applied to the open spaces in Recife.

Table 2: General description and selected data of the experimental areas

Exp. Area	Position	masl	m²	Description
1	S8 01 16.3 W34 56 32.6	50	625	Forest in medium development stage
2	S8 01 19.1 W34 56 27.0	58	625	Forest in initial development stage
3	S8 01 21.1 W34 56 28.4	60	625	Perennial crops, fruits
4	S8 01 19.9 W34 56 34.7	57	625	Public recreation area
5	S8 01 29.5 W34 56 20.6	8	625	Public recreation area
6	S8 01 36.9 W34 56 09.1	23	625	Fallow land
7	S8 01 17.8 W34 56 14.6	30	625	Fallow land
8	S8 01 25.1 W34 56 37.4	23	9000	Shade trees on public streets (Rua de Apipucos + Rua Dezessete de Agosto) (Total 3 km)
9	S8 02 30.1 W34 54 14.4	14	9000	Shade trees on public streets (Rua Rosa e Silva) (Total 3 km)
10	S8 00 25.1 W34 57 56.3	28	625	Perennial crops, fruits
11	S8 00 27.4 W34 57 53.4	21	10	Annual crops, Cassava
12	S8 00 24.7 W34 57 51.1	40	625	Fallow land
13	S8 00 25.0 W34 57 54.2	30	625	Fallow land
14	S8 00 23.9 W34 57 48.8	41	625	Forest in initial development stage
15	S8 01 38.1 W34 56 53.2	10	625	Annual crops, vegetables
16	S8 01 15.0 W34 56 25.3	12	625	Private recreation area
17	S8 01 16.4 W34 56 08.0	12	150	Private recreation area
18	S8 01 24.8 W34 56 59.5	13	625	Fallow land
19	S8 01 11.0 W34 56 51.2	21	625	Public recreation area
20	S8 01 12.6 W34 57 10.2	15	625	Public recreation area
21	S8 01 23.9 W34 56 26.6	30	625	Fallow land
22	S8 01 23.8 W34 56 32.3	37	625	Perennial crops, fruits

4.4 Characterization of the experimental systems

4.4.1 Natural Forest

This experimental system represents the natural vegetation of Recife, the mata atlantica. In fact the selected plots represent forest fragments conserved in an urban landscape. The classification of the development stage is rather subjective according to the tree sizes and the fragment size. These fragments are located mostly on private land like in the “Maristas” University and in protected areas like the “Mata dois irmaos”. In this research they were considered as a reference represent the potential of open spaces with their functions and dynamics as close to equilibrium as possible considering the urban scenario.

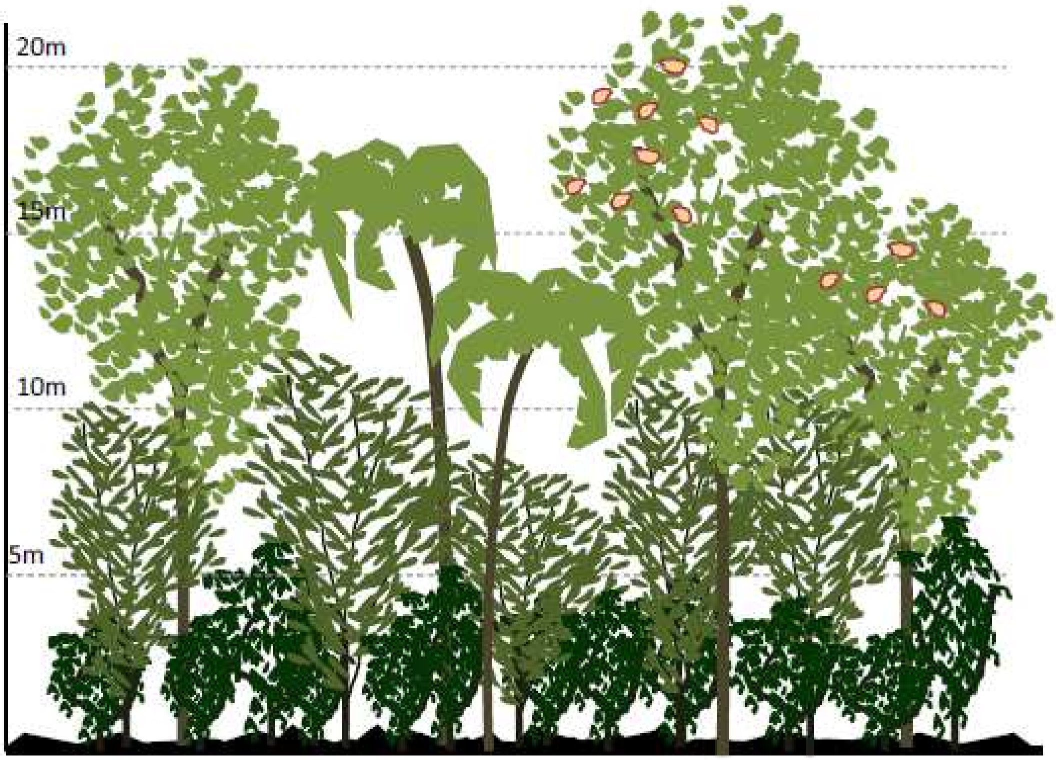


Figure 12: Characterization of the natural forest system.

4.4.2 Fallow land

This are abandoned areas without a defined use neither maintenance nor any kind of management. The areas studied here are private owned. They could be considered as the very beginning of a natural regeneration.

Unfortunately they are often used to store scrap or as a pathway by the neighbors. The vegetation is mostly composed of grasses and small bushes, sometimes also trees which are left-over's from further uses like Eucalyptus trees.

The owners seem to speculate with better land prices so they can sell these areas for building purposes.

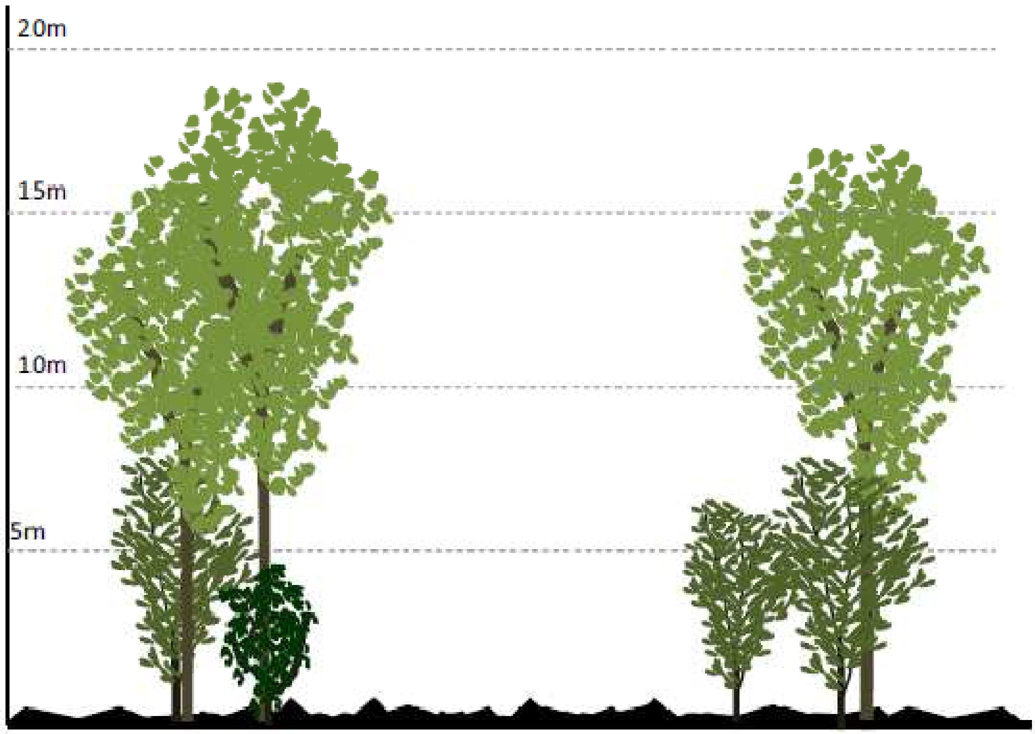


Figure 13: Characterization of the fallow land system.

4.4.3 Perennial crops

Fruit trees can be found in almost all experimental systems but the perennial crops systems do have the finality of providing certain subsistence. They are planted by farmers in the peri-urban region of Recife but also some back-yards have small plantations. All of them are managed in a very extensive way, without heavy inputs as fertilizers or pesticides.

Important are Bananas (*Musa* spp.), Mango trees (*Mangifera indica*) and Jack fruit trees (*Artocarpus heterophyllus*). Many of them are collected and sold in the city directly to the consumers. Yet, most of them are consumer in the households where they are produced.

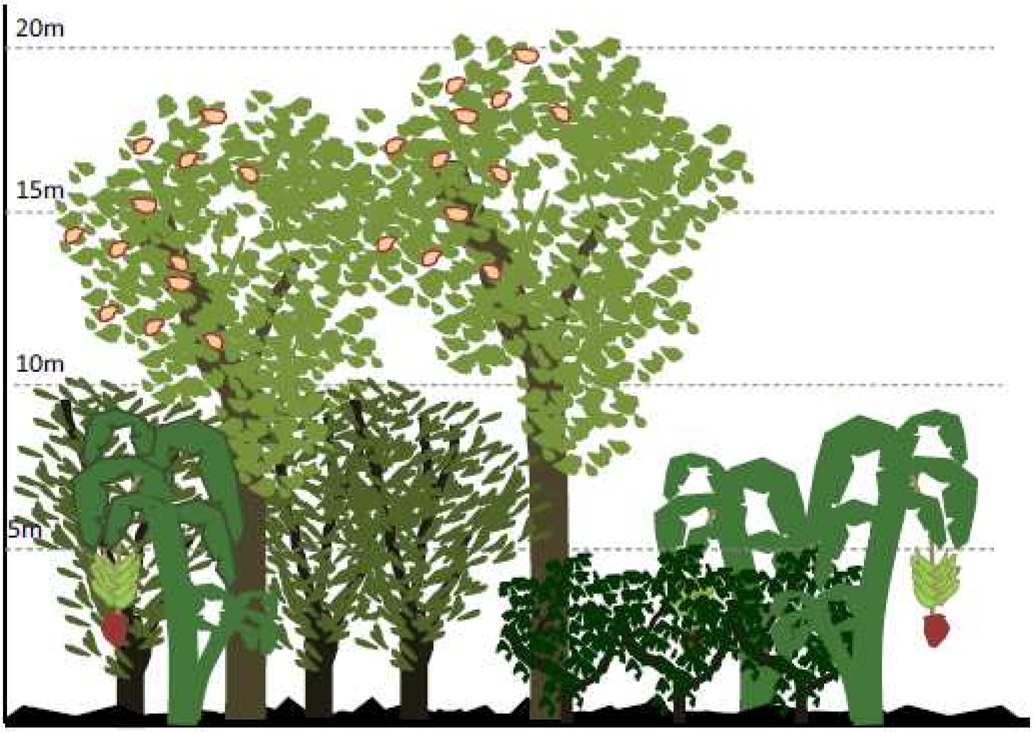


Figure 14: Characterization of the perennial crop system.

4.4.4 Annual crops

Partly produced for the own consumption but in some cases produced commercially like in the CEASA area. Urban farmers take advantage of the short cycles (seven harvests per year) of vegetables and the good acceptance of cassava (*Manihot esculenta)* in the local markets.

Some are located very close to the CEASA where they can be sold directly to the consumers. In these cases the areas are completely specialized to produce annual crops with no attention to other land uses.

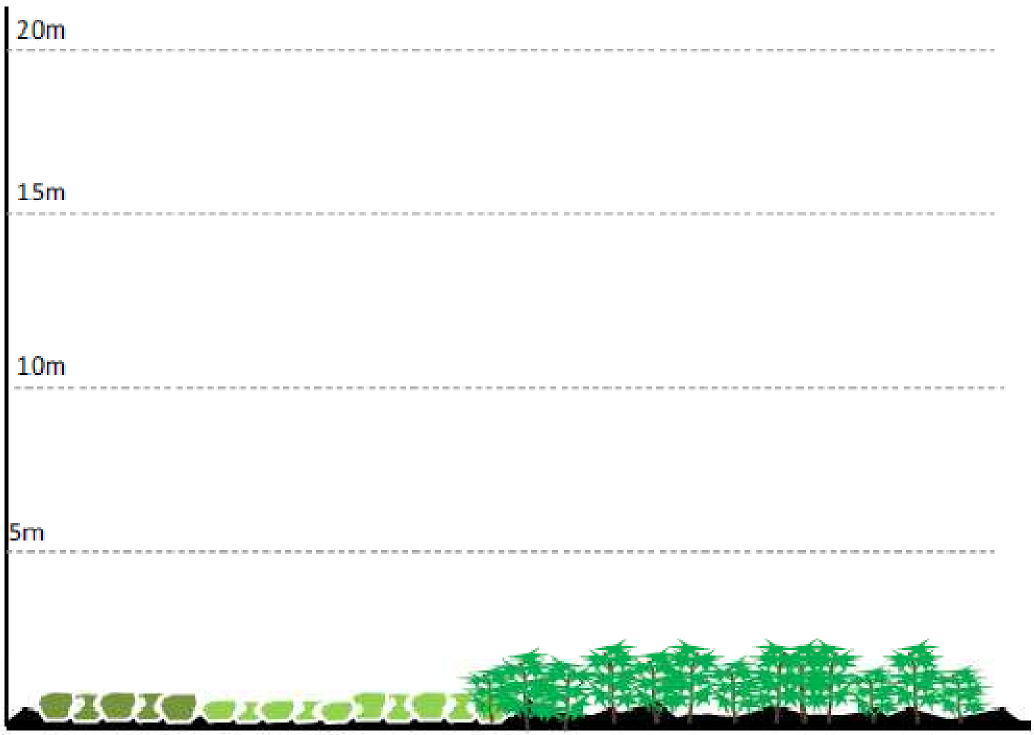


Figure 15: Characterization of the annual crop system.

4.4.5 Recreation areas

Recreation areas are public or private areas dedicated to recreate like parks in the community or small gardens in the backyards of private households. Typically they are dominated by ornamental plants that should provide beauty, relaxing and shade.

Sometimes they are equipped with garden furniture or small play grounds for children to play. Usually the ground is covered by ornamental grasses and the maintenance is kept by public services or by the households themselves.

Trees are pruned from time to time and the grass is maintained short. Spontaneously some fruit trees can occur but they are not the central use of these areas.

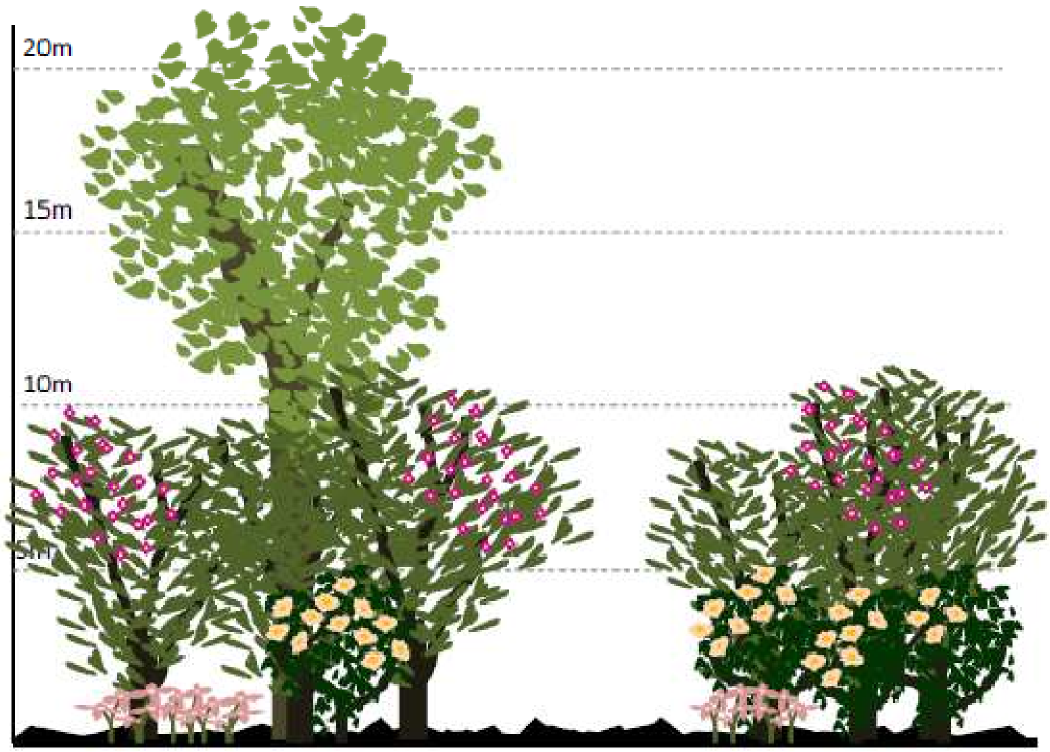


Figure 16: Characterization of the recreation area system.

4.4.6 Street trees

Street trees are planted along the sidewalks of many streets in Recife. Since they came after the street was build, many of them are not that developed. They are part of the urban environment and found around the whole city. The decision of whether which tree to plant is based on its ability of providing shade.

As well important is its phenological development because too tall trees can grow up to the power lines and thus create extra costs to the public services to maintain them short. In the ideal case small species are chosen from the beginning.

Another aspect is that usually they are not fruit trees because falling fruits could be a danger for the passing traffic and when lying on the ground they can create another cost factor when cleaned up.

Figure 17: Characterization of the street tree system.

4.5 Ecological valuation of the experimental systems

4.5.1 Strata-1, Biomass assessment of the soil litter and herbaceous vegetation assessment

The quantification of biomass stored in the soil cover and herbaceous vegetation was made by partitioning this layer into four different pools:

- Fine litter (dead leaves and fine twigs)
- Coarse litter (twigs and wood fragments)
- Monocotyledonous plants
- Dicotyledonous plants

In each experimental area, four areas of 1m x 1 m were randomly defined. Areas with extreme deviations and not representative areas were avoided. The whole biomass from this m² was packed into four plastic bags, each representing one of the pools mentioned above. Plants were cut at soil level. The material was taken to the laboratory from the forestry department at the federal university of Pernambuco. There, each bag was weighed to determine the fresh mass of the samples. Afterwards each sample was oven dried at 65°C until it reached a constant weight which is the dry mass. The data was registered in Excel spread sheets and the resting values of biomass in each pool were up scaled to an area of one hectare.

The methodology applied to the annual crops system was quiet different, that why it is described separately in the next chapter.

4.5.1.1 Biomass assessment of the soil litter and herbaceous vegetation in the annual crops system

In the annual crops system a different procedure was applied because of the homogeneity and predictability of this systems. Two principal types of annual crops systems were identified which were mainly cassava plantations and vegetable plantations.

To characterize the cassava plantations in their structure and biomass a representative plantation area was selected and 9 random samples of cassava plants were harvested at a commercial development stage. The DBH and the plant height were measured in each sample. After the harvest, the whole plants were taken to the laboratory of the federal university of Pernambuco in Recife and separated into roots, stems and leaves. Each part was weighed to determine the fresh mass (FM) and afterwards dried at 65°C in an oven until the samples reach a constant weight to define the dry mass (DM). The plant density was defined by counting the plants in 10 meters of the row and measuring the distances between rows at 10 different random points. The plant density as well as the DBH, the FM and the DM were up scaled mathematically to a hectare basis. Differently than in the other systems the survey was made only once at the commercial harvest time.

Since the production cycle of the cassava plant varies between 10 and 20 month, depending on the variety but it can be cultivated (planted and harvested) across the whole year (Gomes 2003), after talking to farmers a cycle of 12 month was assumed. The farmers confirmed this cycle as realistic because in 12 month the roots reach the ideal size for the market. According to the questionnaires applied, there is no systematic cropping calendar for the cassava, usually there are two planting actions across the year and respectively two harvest actions in each farm.

Assuming the plantation and harvest taking place at the month of March and September, the total biomass from a cassava plantation at harvest was distributed in equal amounts in this two month to make a comparison with the other systems possible. Since the harvested part is the root, it was assumed that the leaves and the stem remain on the field during the month following the harvest. Leaves were considered as fine litter and stems as coarse litter.

The biomass data of the strata-1 in vegetable production systems was taken from Mayer (2009). He defined typical vegetable production systems in Brazil and evaluated them by a very similar methodology as described in chapter 4.5.1 of this thesis. Mayer subdivided the vegetable biomass into the harvested or commercial part, stems and residues left after harvest on the field. He weighted each part fresh and the dried them at 65°C in an oven until the gets is constant to determine the dry mass. The most important vegetables cultivated and considered in this thesis were Lettuce and Chinese cabbage, the same as in the work of Mayer. According to the farmers in the study area the cycle of the vegetables is of 50 days, meaning that in one year 7 cycles can be completed on the same area.

To make the biomass stock in vegetable plantations comparable to the measurements from other experimental systems, the full biomass at harvest was considered in the month of March, April, September and November.

To describe the biomass stocks of the "annual crops system" a mean value between cassava and vegetable areas was considered, since those are the principal systems composing and rotating in different proportions on the cultivated areas found in Recife.

4.5.2 Strata-2, 3 and 4, Biomass assessment of the wooded plants and arborous vegetation

To estimate the aboveground biomass of trees, an algometric equation was applied. Hairah et al. (2001) gives a good definition about algometric relationships: "The scaling relationships, by which the ratios between different aspects of tree size change when small and large trees of the same species are compared"

To obtain aboveground tree biomass in this study, the equation from Brown et al. (1995) for moist areas (1500-4000 mm rainfall/year) was used, because of the availability of the tree height, what gives us more precise aboveground biomass estimation (Hairah et al. 2001). The equation is expressed by the formula:

$$W = 0.049\, \rho\, D^2\, H$$

where W = tree biomass (kg/tree), ρ = wood density (g/cm^2), D = diameter at breast height (DBH in cm) and H = tree height (m). Wood densities were taken from the ICRAF website (http://www.worldagroforestry.org/sea/Products/AFDbases/WD/Index.htm).

For the trees were a wood density or the species could not be identified a medium density of 0.5 gr/cm^2 was considered. In each experimental area, all trees were marked and the stem circumference measured at 1.30m from the soil, and converted to diameter at breast height (DBH), dividing the circumference through π (3.141592654). The stem and the total tree height was measured with a Clinometer from SUUNTO, model PM/1520 P with 0.5 m precision and a fix distance to the tree of 15 m.

The crown radius of each tree was measured in four directions and the circular crown area than calculated using the mean radius.

4.5.3 Spatial system analysis

4.5.3.1 Eco-volume (V_{eco}) and bio-volume (V_{bio})

Eco-volume (V_{eco}) is the space in which a plant or vegetation interacts with biotic and/or a-biotic factors such as sunlight, wind, water, biodiversity and even mankind. Bio-volume (V_{bio}) is the space occupied by the biomass of a plant. This approach described in Janssens (2004) follows the principle that a vegetation stand does not optimize the energy fluxes to produce a two dimensional output or product presumed by most indicators like the leaf area index and basal area, but to colonize a three dimensional space and developing the maximum V_{eco} with the minimum of energy. Even though, the maximum power principle, explained by Odum (1995) as:

"During self organization, system designs develop and prevail that maximize power intake, energy transformation, and those uses that reinforce production and efficiency"

could be confirmed in Benin (Figure 18) and holds on a two-dimensional system analysis methodology. In the case of Benin it is possible to see that the forest is the best accumulator of energy (biomass expressed in t/ha and NPP in t/ha/y) on a two-dimensional basis. (Janssens 2009). Yet the same Figure 18

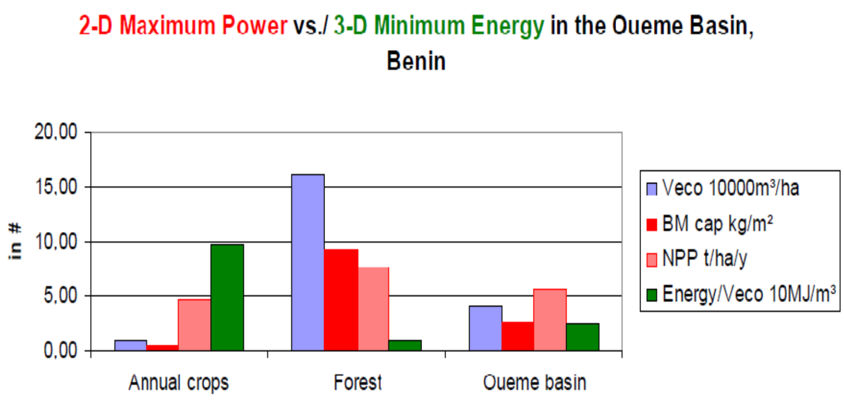


Figure 18: Energy allocation in agro-ecological systems is in fact bound. Source: Janssens 2009.

shows that when the energy stocks and fluxes are considered to supply a three-dimensional space (V_{eco}) instead a plane area (ha) the forest stand is the system with less energy per unit of V_{eco} (expressed in m^3), reinforcing the minimum energy principle and the second law of Thermodynamics also explained as:

"The natural vegetation tends to evolve towards maximizing its eco-volume at least energy per unit. Plant growth is in fact the developing of a maximum eco-volume with a minimum energy" (Janssens 2004)

In this work different three dimensional parameters were measured as follows:

The eco-volume (V_{ecoi}) of an individual plant is the volume in m^3 that results from multiplying its height (H_{ecoi}) in meters with its crown area (CA) in square meters:

$$V_{ecoi}\ (m^3) = H_{ecoi} \times CA$$

Yet, the eco-volume of a whole stand (V_{ecos}) is calculated by multiplying the eco-height of the stand (H_{ecos}) in m^2 with the total area of the stand (SA):

$$V_{ecos}\ (m^3) = H_{ecos} \times SA$$

The bio-volume (V_{bio}) is the volume occupied by the biomass stored in one plant. It is calculated by the formula (Janssens et al. 2004):

$$V_{bio} = H_{ecoi} \times BA$$

Where BA is the basal area of the stem taken at soil level (Torrico 2009) or, like in this case, at breast height.

Baumert (2008) recommends weighting the H_{ecoi} with the BA to get the H_{ecos} when the stand is not considered as closed by the canopies of the trees. This means to use the formula:

$$H_{ecos} = \Sigma\ V_{bioi} / \Sigma\ BA$$

4.5.3.2 Important indicators for the spatial system analysis

After the three dimensional description of the different experimental systems mentioned here it is possible to relate V_{eco} and V_{bio} to create important indicators and rank the efficiency of those systems. The first indicator is the so called "Wesenbergfaktor" that reflects the ability of a plant or a stand to colonize space. The "Wesenbergfaktor" is calculated by the formula:

$$W_b = V_{eco} / V_{bio}$$

The other important indicator is the crowding intensity (C_i) expressed as the percentage of the V_{eco} occupied by the V_{bio}:

$$C_i = 100 / W_b$$

The C_i is a quality indicator of the V_{eco}. In natural systems the C_i tends to increase over time up to a point where equilibrium is reached between the biotic and a-biotic elements interacting in the system. Yet, in agricultural and manmade systems the C_i tends to be pushed by external inputs such as fertilizers with the objective to reach a higher harvest index per area (Janssens 2004). Similar to the C_i it is possible to calculate the resilience of a system that is considered by Torrico (2006) to be the capacity of a system to endure stress and bounce back, in other words:

"The more resilient the ecosystem, the faster its capability to return to its original long-lasting equilibrium state; the bigger its ability to tolerate changes, disturbances and stresses, the higher the probability of the ecosystem being able to maintain efficient functioning"
(Torrico 2006)

The resilience (R) expressed in % is calculated like the C_i, but V_{eco} of the actual stand is substituted by the potential V_{eco} (V_{pot}). The Vpot is the same as the V_{eco} when the system is in complete equilibrium, or in its original state in nature. When comparing the resilience of different systems it is possible to rank them according to their ability to resist ecological disturbances and its ability to return to its equilibrium state:

$$R_i = 100 / (V_{pot} / V_{bio})$$

In fact, Torrico (2006) could confirm a linear relation between the resilience of 17 different land use systems around the world and the species richness in these systems (Figure 19).

Agricultural systems	Resilience (%)	Richness
Grass system	0,005	8
Citrus	0,006	8
Fruit Vegetables	0,012	19
Mixed Vegetables	0,013	21
Leaf Vegetables	0,014	19
Sylvopastoral	0,029	34
Ecological	0,124	96
Coffee Chiapas-Mexico	0,142	99
Cocoa Agro-forest	0,220	120
Coffee Nordeste-Brazil	0,411	122
Caatinga Teresina-Brazil	0,052	16
Water plants	0,054	6
Regeneration forest (3 y)	0,088	30
Forest Uganda	0,154	43
Forest fragment Chiapas	0,198	64
Fragments Mata Atlântica	0,365	110
Forest Mata Atlântica	0,630	263

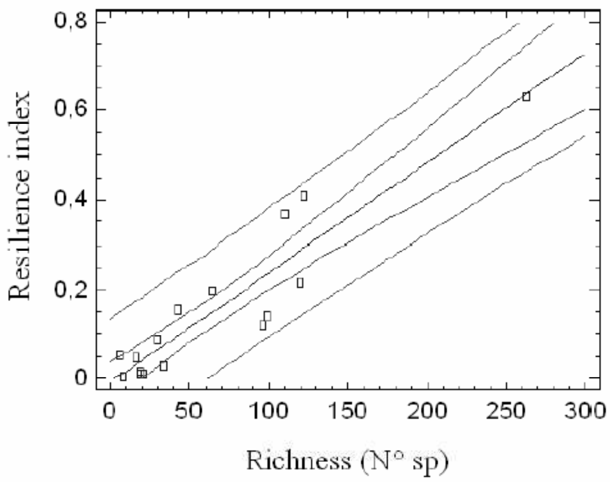


Figure 19: Simple Regression - Resilience index vs. Richness. Source: Torrico 2006.

The output of Figure 19 shows the results of fitting a linear model to describe the relationship between resilience index and richness. The equation of the fitted model is resilience index = -0.0075 + 0.0024*richness. Correlation coefficient = 0.934, Rsquared = 87.3 percent.

The author grouped the resilience in four categories where systems with values above 0.5 are approaching climax, between 0.3 and 0.5 possess a high resilience capacity, between 0.1 and 0.2 possess an average and smaller than 0.1 possess a low resilience capacity.

4.5.4 Biodiversity assessment

Schmidt (2007) realized a biodiversity survey in the scope of her master thesis in the open spaces of Recife. Her research was made in the region of "Apipucos", the same as where some of the experimental areas of this thesis are located. In fact, some of the experimental areas are exactly the same. She grouped her 16 experimental areas into nine different experimental systems (Table 3):

Table 3: Biodiversity data assessment

Nr.	Experimental systems (Schmidt, 2007)	Nr.	Experimental systems (Author)	Data transfer (source)	Dataset
1	Forest fragments (private and public).	1	Natural forest	Schmidt (2007) (mean values)	1- List of species (by family) 2- Species richness (nr.) 3- native/exotic origin (%) 4- species use (Type)
2	Fallow land in initial development stage	2	Fallow land		
3	Fallow land in advanced development stage				
4	Subsistence agriculture	3	Perennial crops	Author (field survey)	
		4	Annual crops		
5	Private gardens	5	Recreation areas	Schmidt (2007) (mean values)	
6	Public recreation areas				
7	Side walks	6	Street trees		
8	Riparian vegetation (mangroves)			____	
9	Abandoned industrial areas				

For four of the six experimental systems in this thesis the biodiversity data was transferred from Schmidt (2007). Only the agricultural land use systems were sub-divided into perennial and annual crops and the data is resulting from own field surveys. The reason is that from the biomass management point of view the annual and perennial crops, even if the use is for food in both, they are submitted to totally different treatments what results in different ecological interactions and functions. The most important output of this survey is a list of species per land use system, their richness, the origin (if native or exotic) and the general use of each species.

4.5.5 Carbon assessment

To determine the total carbon stored in the respective land use systems analyzed, the dry biomass measured in one hectare was multiplied by the factor 0.5 (Schlesinger 1991) to get the carbon stored. Considered were the above ground stored carbon (in t/ha), the yearly fixed carbon (in t/ha/y) and the carbon exported yearly from the systems (in t/ha/y).

4.5.6 Estimation of the cooling potential

The cooling effect of vegetation happens through evapotranspiration (EVT) and shading of the surrounding surface. EVT is strongly correlated to the carbon fixation rate of vegetation stands (C_{fs}). Theoretically it is possible to calculate the amount of water that is evapotranspired by plants if the carbon fixation rate and the water use efficiency (WUE) is known. Yet, the WUE varies between single species (Cernusak 2010) and is influenced by air temperature, vapor pressure deficit, net radiation (Yu et al. 2008) CO_2 concentration in the atmosphere, nitrogen deposition and management practices such as irrigation (Tian et al. 2010). Depending on the structure, those factors can vary across the stand due to the microclimate created under a closed canopy (Tollenaar 2008). All together makes a modeling of WUE in complex ecosystems very difficult. In this research the cooling effect from EVT was not measured in absolute but in relative values to make the experimental systems comparable and will be based on its strong relation with the C_{fs}. The microclimate created by the cooling effect of EVT will be delimited

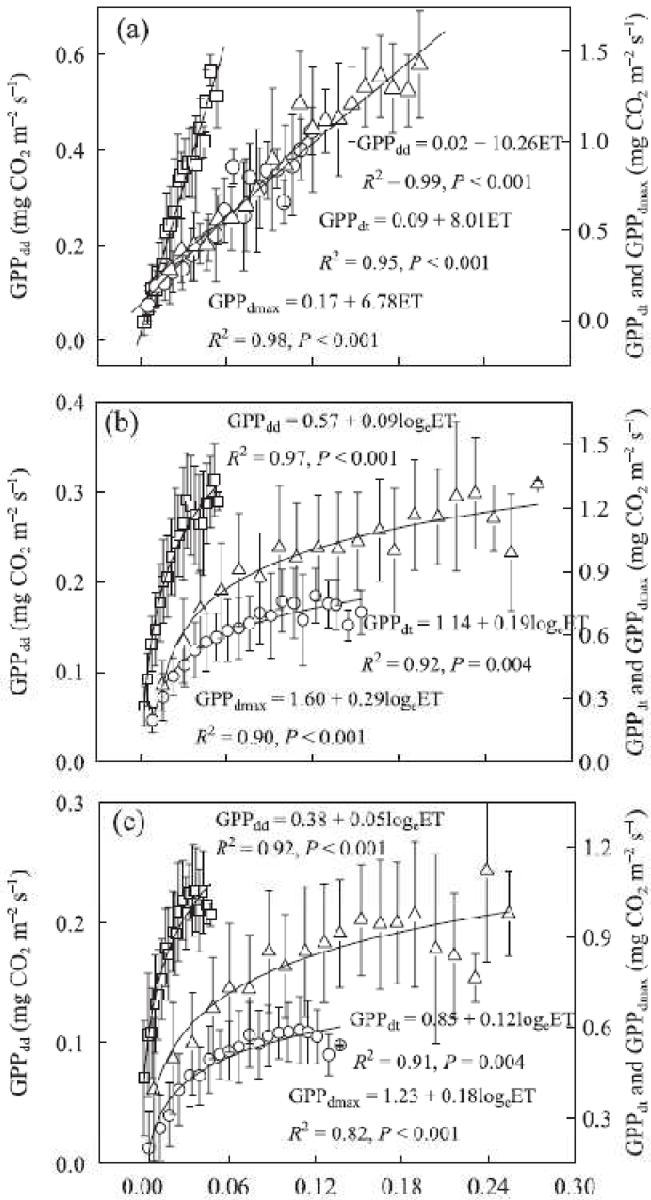


Figure 20: The relationships between gross primary productivity (GPP) and evapotranspiration (EVT) in three different stands and at three different time scales. Source: Yu et al. (2008).

in its size by the volume enclosed by the canopy (confinement facto) of the stand, thus the cooling potential of EVT (ECP) was determined as:

$$ECP_i = C_{fs} \times V_{ecos}$$

Where ECP_i is the evaporative cooling potential index, C_{fs} is the carbon fixation rate of the stand and V_{ecos} is the eco-volume of the stand.

Shading depends on the density and size of the plants. A higher interception of direct and reflected solar radiation (reduced transmission) is related to a high crown density and the continuous and grouped disposition of plants in the stand (Scudo 2002). Figure 21 shows the effect of the density of the canopy on the surface temperature of streets. The height and the area of the crown determine the projected size of the shaded area affected by the reduced radiation (Figure 22).

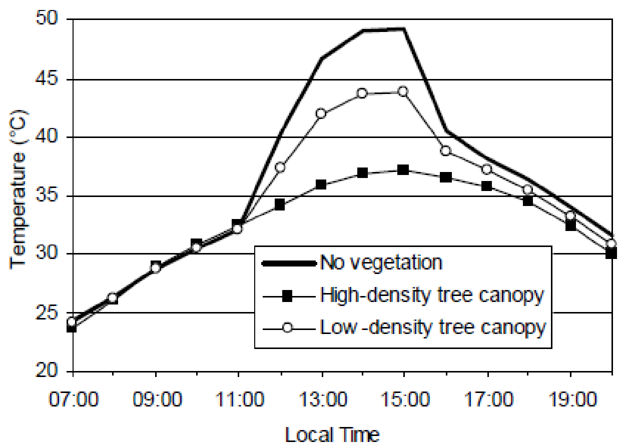


Figure 21: Influence of canopy density on street surface temperature reduction through shading. Source: Spangenberg et al. (2008).

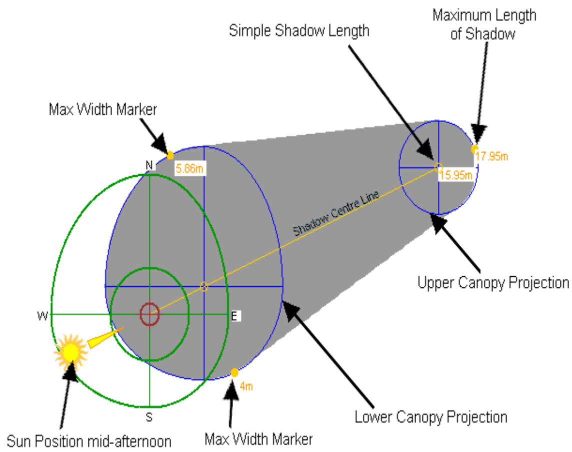


Figure 22: Influence of canopy height and area on the shading performance of a single tree. Source: Skellern (2011).

The density of the whole stand is expressed by the crowding intensity explained in chapter 5.3. Since all stands are assumed to have the same area for comparison purposes, only the stand height will be considered as having an influence on the shading potential, thus the shading potential index (SP_i) of the experimental systems was determined as:

$$SP_i = C_{is} \times H_{ecos}$$

Where SP_i is the shading potential index, C_{is} is the crowding intensity of the stand and H_{ecos} is the height of the stand.

To enable an estimation of the relative cooling potential across the experimental systems considering the aspects of evaporative cooling and shading, the total cooling potential index (CP_i) was defined as:

$$CP_i = ECP_s \times SP_s$$

Where CP_i is the estimated cooling potential index, ECP_i is the evaporative cooling potential index and SP_i is the shading potential index.

4.6 Characterization of the cases

To analyze the potential of open spaces to store carbon and there ecological implications, six areas were analyzed in detail.

The criteria of selecting those areas were that:

- they should represent the transition zone between urban and rural around Recife
- they should represent typical landscapes with a broad diversity of land uses
- they should represent different social realities and regions from Recife

<u>The first step</u> to select the six areas was to decide for an overall transect where this areas should be found. The transect chosen is located in the NW part of Recife and extends along a virtual line from SE to NW that starts at S 8 02 14.7 and W 34 54 01.7 and goes up to S 7 54 01.0 to W 34 58 37.9.

In the southern part of this area the landscape is typically urbanized with dense housings, paved roads and all possible public services available like public transport, recreation possibilities, commercial areas, etc.

In the centre of this area the “Mata dois irmaos”, a protected area creates a green spot of mata atlantica fragments in the city. The housings are also dense like in the southern part but settlers are adapted to very green environments due to the “parque dois irmaos” and other large green areas like the federal university of Pernambuco.

At the northern part the landscape starts to have more rural characteristics with agriculture, less dense housings and many time unpaved roads and reduced public services. Even though, this area is inhabited by urban settlers that try to live a more nature oriented life even if they do not practice agriculture.

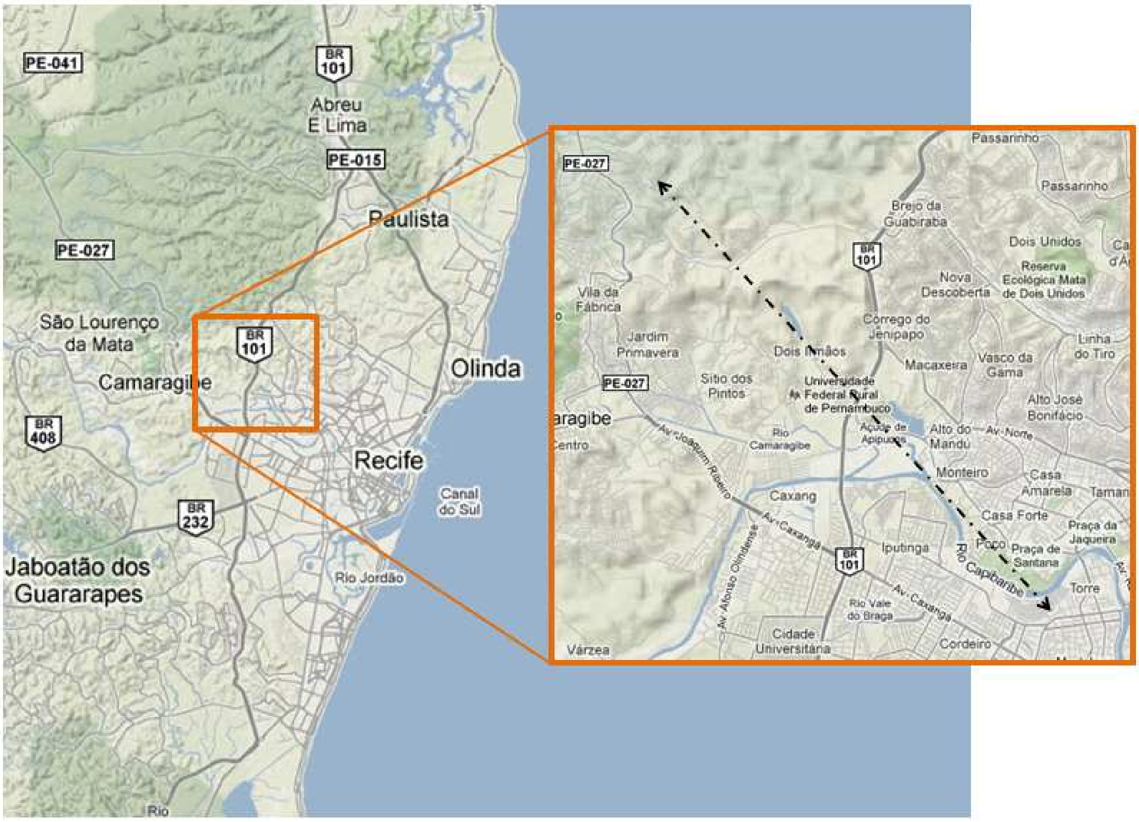


Figure 23: Map of Recife and illustration of the experimental transect. Source: maps.google.com

<u>The second step</u> was to apply a questionnaire (Annex 1) that should help to understand the different realities. The questionnaire was applied to 122 family leaders, each representing one single household or farm. The most important information got can be divided into two groups:

1. Social aspects like number of people in the house, income, migration patterns, origin and motivations
2. Land use aspects like plot area, land use systems, management forms of open spaces

The third step was to decide for certain neighborhoods which represent the whole area under the criteria mentioned above. The six areas chosen were:

- Estrada dos macacos
- Assentamento macacos e pedreiros
- Apipucos
- Aldeia
- CEASA
- Ilha dos bananais

The six areas are described in detail in chapter 6.

A social profile for each area was drawn to explain the reality and a little of the historical reasons for that area to be like it is. Afterwards each area was evaluated for its ecological aspects like carbon storage and other aspects of the land use systems applied using the data from chapter 4.5 which analyses each land use system in detail.

The principal indicators of each land use system (Eco volume, crowding intensity, carbon stock and resilience index) were weighted by the area represented by each land use system in each household and an ecological profile could be drawn for each case.

5 RESULTS AND DISCUSSION

In this chapter the data acquired from the field measurements in the 22 experimental areas will be presented and statistically evaluated. The quantified carbon stocks and ecological implications will be discussed for each of the 6 selected experimental systems.

5.1 Two-dimensional biomass structure in the land-use systems

The two dimensional approach is based on standard measurement techniques already used in forestry to determine biomass and structure of different systems to make them comparable. The resulting data is expressed in units per area, in this case, units/ha.

5.1.1 Soil cover and herbaceous plants across the year (Strata-1)

5.1.1.1 Strata-1 in Natural forest systems

The natural forest system has a soil cover including fine/coarse litter and mono/dicotyledonous plants in the first layer (or Strata-1). Strata-1 has a fresh mass of 9.98 t/ha and a dry mass of 3.02 t/ha. These are mean values for the Strata-1 across the year. If each component is considered separately, the most contributing is the fine litter with 5.49 t/ha FM (1.75 t/ha DM) followed by the coarse litter with 2.54 t/ha FM (0.83 t/ha DM), dicots with 1.39 t/ha FM (0.29 t/ha DM) and monocots with 0.57 t/ha FM (0.15 t/ha DM). While fine and coarse litter biomass increase from the beginning to the end of the year, mono- and dicot biomass is reduced, probably due to the suppression caused by fine and coarse litter (Table 4).

Table 4: Biomass pools of strata-1 in the natural forest systems across the year

Biomass	Fine Litter		Coarse Litter		Monocots		Dicots	
in t/ha	FM	DM	FM	DM	FM	DM	FM	DM
March	2.91	1.10	0.85*	0.31*	1.74*	0.44*	2.03	0.44
April	3.85	1.05	2.77	0.77	0.52	0.17	1.45	0.34
September	4.97	1.65	2.29	0.91	0.00	0.00	0.93	0.18
November	10.23*	3.21*	4.23*	1.32*	0.00	0.00	1.13	0.20

*These values are significantly different at a 95% confidence level (LSD)

5.1.1.2 Strata-1 in perennial crops systems

The perennial crop system stores a fresh mass in the first layer (Strata-1) of 7.55 t/ha and a dry mass of 2.40 t/ha. The most important component in Strata-1 is the biomass from monocots (3.95 t/ha FM and 1.64 t/ha DM) followed by fine litter with 1.66 t/ha FM (0.35 t/ha DM), dicots with 1.24 t/ha FM (0.26 t/ha DM) and coarse litter with 0.70 t/ha FM (0.15 t/ha DM).

Due to the fact that this system is an artificial man-made production system, the amounts of biomass do not differ significantly between the samples. Not even a significant change in the biomass pools could be observed across the year what indicates a very homogeneous biomass structure in the Strata-1 layer. The higher amount of monocots compared to the biomass from dicots indicates reflects the agricultural practices applied to this areas to maintain the soil cover "clean" and free from bushes or other plants that could dispute for the nutrients with the crops (mainly banana, Mango, Coco-nuts and Cassava plants). Table 6 shows that there is no significant change in the different biomass pools of Strata-1 in the perennial crop system when observed across the year.

Table 5: Biomass pools of strata-1 in the perennial crop systems across the year

Biomass	Fine Litter		Coarse Litter		Monocots		Dicots	
in t/ha	FM	DM	FM	DM	FM	DM	FM	DM
March	1.87	0.46	0.51	0.13	3.97	1.32	1.35	0.30
April	1.30	0.29	0.60	0.13	3.81	2.01	1.21	0.28
September	1.60	0.27	0.81	0.17	4.30	1.97	1.07	0.20
November	1.88	0.38	0.88	0.16	3.71	1.25	1.31	0.26

*These values are significantly different at a 95% confidence level (LSD)

5.1.1.3 Strata-1 in recreation area systems

In the Strata-1 of the recreation areas a total fresh mass of 3.04 t/ha (1.15 t/ha DM) was measured, which is very low compared to the other systems. When each component is considered separately, the most contributing is the fine litter with 1.58 t/ha FM (0.40 t/ha DM) followed by the monocots with 0.85 t/ha FM (0.56 t/ha DM), dicots with 0.45 t/ha FM (0.14 t/ha DM) and coarse litter with 0.17 t/ha FM (0.05 t/ha DM).

As well as in the perennial crop system, the recreation areas are artificial man made systems which are maintained by agricultural or horticultural practices. One of those practices is the pruning of trees and of the grass to make a certain comfort level for their users possible. This is the reason why almost no coarse litter was found (pruned material is taken out of the system) and the stored biomass in herbaceous plants (like grass) does not change across the year and between the different seasons.

Table 6: Biomass pools of Strata-1 in the recreation systems across the year

Biomass	Fine Litter		Coarse Litter		Monocots		Dicots	
in t/ha	FM	DM	FM	DM	FM	DM	FM	DM
March	1.55	0.36	0.10	0.03	0.88	0.26	0.58	0.16
April	1.34	0.34	0.30	0.11	1.52	1.05	0.17	0.10
September	1.72	0.42	0.10	0.03	0.29	0.73	0.45	0.14
November	1.70	0.47	0.17	0.04	0.70	0.21	0.58	0.16

*This values are significantly different at a 95% confidence level (LSD)

5.1.1.4 Strata-1 in fallow land systems

The Strata-1 in the fallow land system has a total fresh mass (FM) of 9.08 t/ha and a dry mass (DM) of 2.80 t/ha. When each component is considered separately, the most contributing are the dicots with 3.16 t/ha FM (yet only 0.74 t/ha DM) followed by the monocots with 2.94 t/ha FM (1.12 t/ha DM), fine litter with 2.21 t/ha FM (0.80 t/ha DM) and coarse litter with 0.77 t/ha FM (0.14 t/ha DM). As expected, due to the fact that the fallow land system is not dominated by trees and other wooded plants, there is no suppression of the herbaceous cover plants by dead litter. Instead of that, the mono- and dicotyledonous plants can grow and build the most important contribution to the biomass of Strata-1 in Fallow land areas. Table 7 shows that there is no significant change in the different biomass pools of strata-1 in the fallow land system when observed across the year:

Table 7: Biomass pools of Strata-1 in the fallow land systems across the year

Biomass	Fine Litter		Coarse Litter		Monocots		Dicots	
in t/ha	FM	DM	FM	DM	FM	DM	FM	DM
March	1.46	0.35*	0.26*	0.03*	2.76	0.96	3.00	1.06
April	2.05	0.80	0.55	0.11	4.57	1.79	2.04	0.57
September	2.57	0.88	1.03	0.13	2.38	0.98	1.93	0.44
November	2.76	1.17*	1.23*	0.28*	2.04	0.76	5.68	0.87

* These values are significantly different at a 95% confidence level (LSD)

5.1.1.5 Strata-1 in shade tree systems on public streets

This system has no Strata-1 because these are mostly trees and higher bushes which serve as shade providing elements on the sidewalk. The sidewalk in the experimental areas is made of concrete and completely impermeabilized making a development of herbaceous plants impossible. Also the pruned material of the trees and the fallen leaves are swept away by people that live in the surroundings.

5.1.1.6 Strata-1 in annual crops systems

The biomass survey in annual crops systems is partially experimentally funded, partially literature funded. The total biomass in Strata-1 is composed of mean values between cassava and vegetable plantations. The total fresh mass stored in this system is of 10.01 t/ha and 1.79 t/ha dry mass. The most important pool is the biomass from dicotyledonous plants, basically composed of the cassava plants (in March and September) and the vegetables, with a medium fresh mass of 8.14 t/ha and dry mass of 1.44 t/ha. The fine litter, composed mostly of after harvest residues has a FM of 1.67 t/ha (0.29 t/ha DM). Coarse litter is represented by the cassava stems left after harvest and store 0.20 t/ha FM (0.06 t/ha DM). Due to the intensive management in these systems there are no monocotyledonous plants.

Table 8: Biomass pools of Strata-1 in the annual crop systems across the year

Biomass	Fine Litter		Coarse Litter		Monocots		Dicots	
in t/ha*	FM	DM	FM	DM	FM	DM	FM	DM
March	1.54	0.27	0.00	0.00	0.00	0.00	8.48	1.53
April	1.81	0.32	0.40	0.13	0.00	0.00	7.80	1.35
September	1.54	0.27	0.00	0.00	0.00	0.00	8.48	1.53
November	1.81	0.32	0.40	0.13	0.00	0.00	7.80	1.35

* Source: Mayer 2009.

It is also important to note the accumulated biomass in this system across the year, cassava by instance produces a FM of 1.15 t/ha (0.23 t/ha DM) in the form of roots which are exported from the system and vegetables produce a FM of 151.70 t/ha/y (27.94t/ha/y DM) when 7 cycles are added across the year, including crop residues. This amount of BM is similar to the values found in Janssens (2004) for the same crops (Lettuce = 15.37 t/ha and

Chinese cabbage = 25.31 t/ha/y) and with the analysis of leaf vegetable systems from Torrico (2005) who found a yearly DM production of 23.1 t/ha/y.

5.1.2 Biomass structure of wooded plants and trees (Strata-2, 3 and 4)

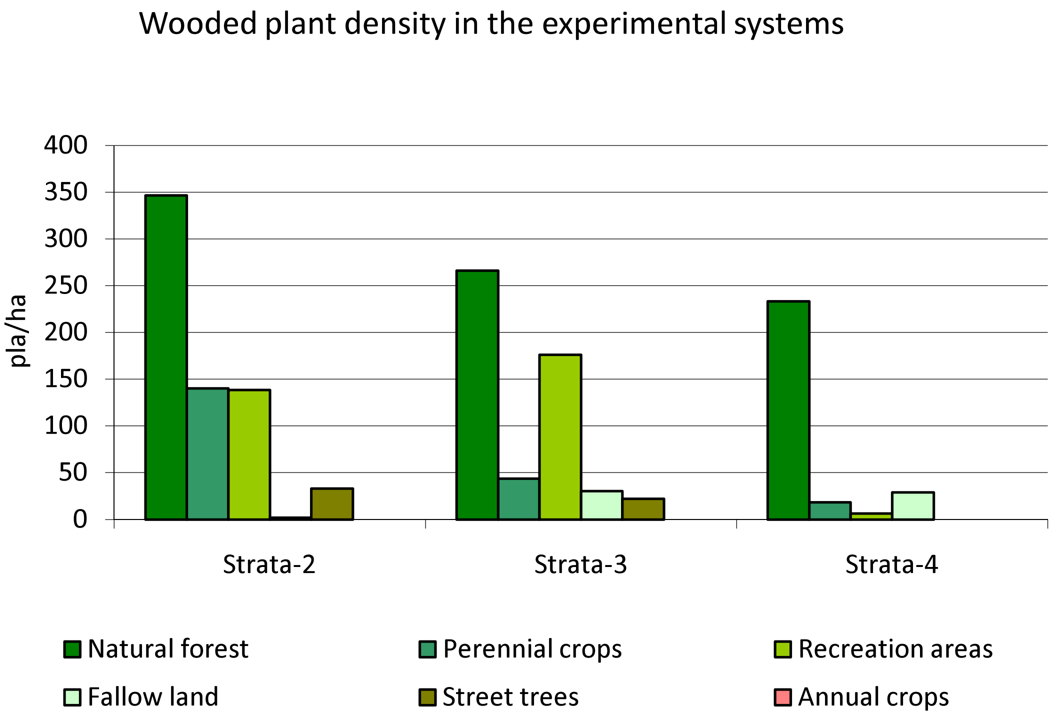
5.1.2.1 Wooded plant density in the experimental systems

There is a huge difference between the systems concerning the plant density on the different layers of wooded plants. The natural forest system has significantly more trees per hectare than the other systems in all strata, with a total of 845.66 pl/ha. Strata-2 has the highest density with 346.51 pl/ha, followed by strata-3 with 266.04 pl/ha and strata-4 with 233.11 pl/ha. The plant density is reduced from the lower to the higher layer.

In the perennial crop system this plant density reduction can also be observed across the strata. Yet, this system has significantly less trees per hectare in each strata making a total of 202.36 pl/ha (strata-2 = 140.24 pl/ha; strata-3 = 43.77 pl/ha and strata-4 = 18.35 pl/ha).

The recreation areas have a total wooded plant density between the natural forest system and the perennial crops system with 320.78 pl/ha. In strata-2 (138.34 pl/ha) there was no significant difference in the plant density if compared with strata-2 from the perennial crops system (140.24 pl/ha).

The significant difference is found in strata-3 where the recreation areas have four times more plants per hectare than the perennial crops system (176.00 against 43.77 pl/ha). In strata-4 this system has only 6.44 pl/ha. Fallow land systems have a total of 61.2 pl/ha being only 2.00 pl/ha in strata-2; 30.40 pl/ha in strata-3 and 28.80 pl/ha in strata-4. The distribution between strata-3 and strata-4 is very homogeneous.



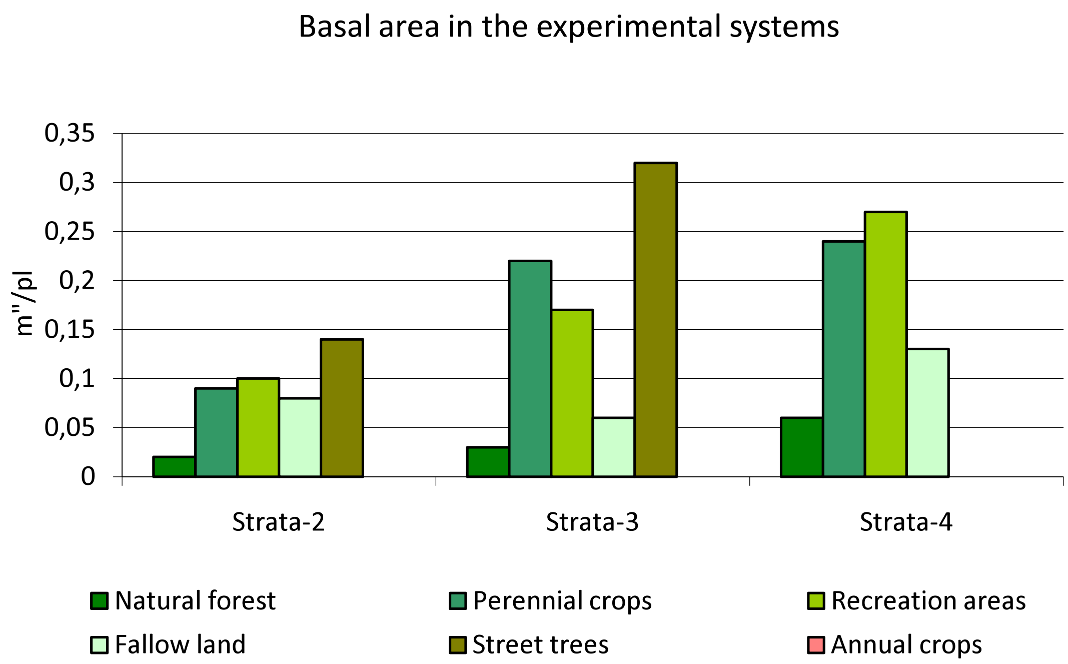
Experimental system	Strata-2	Strata-3	Strata-4	Total
Natural forest	346.51 a	266.04 a	233.11 a	845.66 a
Perennial crops	140.24 b	43.77 c	18.35 b	202.36 b
Recreation areas	138.34 b	176.00 b	6.44 b	320.78 b
Fallow land	2.00 c	30.40 c	28.80 b	61.2 bc
Street trees	33.11 c	22.07 c	0.00 c	55.18 c
Annual crops	0.00 d	0.00 d	0.00 c	0 d

Figure 24: Wooded plant density in the experimental systems. Different letters in one strata are statistically different at a 95% confidence level (LSD).

The most populated strata in the shade tree system are the strata-2 (33.11 pl/ha) and the strata-3 (22.07 pl/ha), ending at a total of 55.18 pl/ha. Annual crops systems have no wooded plant layers so that their density in strata-2, 3 and 4 equals zero.

5.1.2.2 Basal area in the experimental systems

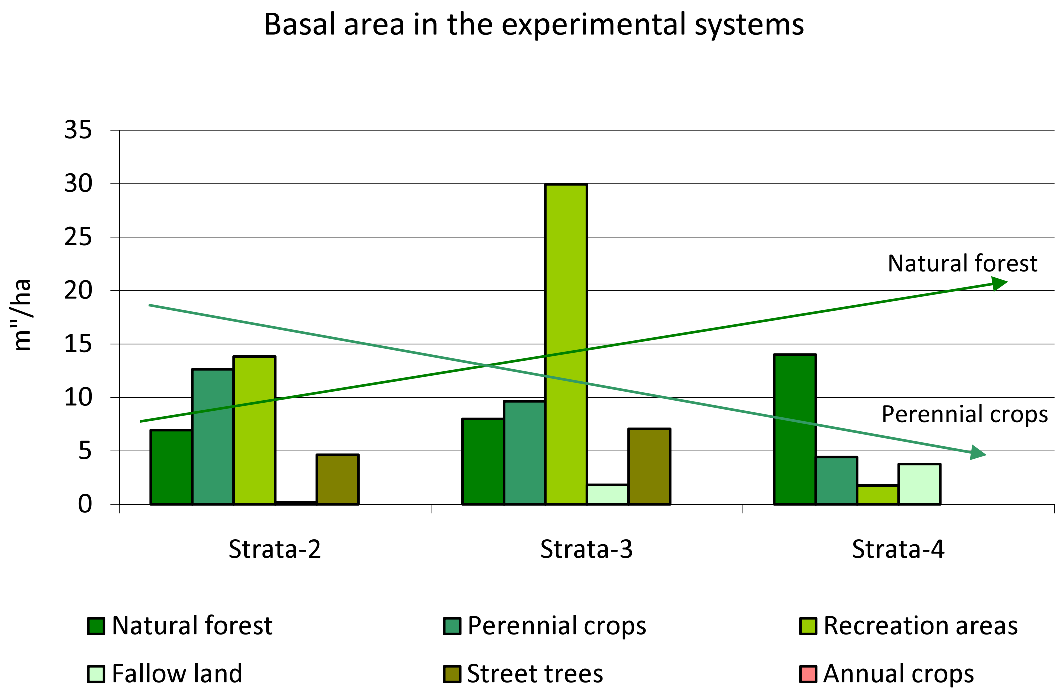
The basal area (BA) of the trees in the different systems and across the different strata is an important element to describe the structure of such systems. Together with the plant heights it explains the development pattern of the system and how the management applied to the systems by man influences this structure. Figure 25 show that BA increases with increasing height of the plants.



	Strata-2	Strata-3	Strata-4
Natural forest	0.02 a	0.03 a	0.06 a
Perennial crops	0.09 ab	0.22 ab	0.24 b
Recreation areas	0.10 b	0.17 b	0.27 b
Fallow land	0.08 ab	0.06 ab	0.13 a
Street trees	0.14 b	0.32 b	0.00 c
Annual crops	0.00 c	0.00 c	0.00 c

Figure 25: Basal area of individual trees in the experimental systems. Different letters in one strata are statistically different at a 95% confidence level (LSD).

As expected, in the natural forest system the added basal area of individual trees in the system increases from strata-2 (6.93 m^2/ha) to strata-3 (7.98 m^2/ha) and to strata-4 (13.99 m^2/ha).



	Strata-2	Strata-3	Strata-4	Total
Natural forest	6.93 a	7.98 a	13.99 a	28.90 a
Perennial crops	12.62 ab	9.63 a	4.40 b	26.66 ab
Recreation areas	13.83 b	29.92 b	1.74 c	45.49 b
Fallow land	0.16 c	1.82 c	3.74 b	5.73 c
Street trees	4.64 a	7.06 a	0.00 d	11.70 c
Annual crops	0.00 d	0.00 d	0.00 d	0.00 d

Figure 26: Sum of the basal areas in the experimental systems. Different letters in one strata are statistically different at a 95% confidence level (LSD).

The perennial crops system shows the opposite, a decrease in the basal area from strata-2 (12.62 m^2/ha) to strata-3 (9.63 m^2/ha) and 4.40 m^2/ha in strata-4. Even with a much inverted distribution across the strata if compared with the natural forest system, the perennial crops system totals a similar basal area (26.66 m^2/ha against 28.9 m^2/ha).

Surprisingly the trees in the recreation area system have a total basal area of 45.49 m^2/ha, almost twice as much as the natural forest system. This huge difference is specially caused by trees from the strata-2 (13.83 m^2/ha) and strata-3 (29.92 m^2/ha). Basal area of trees in Strata-4 (1.74 m^2/ha) is the lowest between the systems that have this strata. This is due to the very low density of trees with more than 15 m height in recreation areas. Even though, the few trees that are there (6.44 pl/ha) have also larger BA than this trees (> 15 m) in other systems.

As well as in the natural forest system, the basal area in the fallow land system increases from strata-2 (0.16 m^2/ha) through strata-3 (1.82 m^2/ha) to strata-4 (3.74 m^2/ha). Yet, even with the same tendency, the fallow land system has the lowest total BA of all systems (5.73 m^2/ha)

The street tree system has the largest BA concentrated in strata-2 (4.64 m^2/ha) and strata-3 (7.06 m^2/ha), a similar tendency as in the recreation areas system but with younger, less developed trees. The annual crops system, as mentioned in chapter 5.1.2 does not have strata-2, 3 and 4.

5.1.2.3 Tree height in the experimental systems

In chapter 4 it is already mentioned that each tree was classified into one of the three strata based on its height. This means that certain linearity between tree height and strata is expected.

Even though there are some differences between trees belonging to one system to trees belonging to another system inside the same strata.

Generally the trees in strata-2 have a medium height of 2.48 m, trees in strata-3 have a height of 9.86 m and trees in strata-4 have a height of 19.59 m. Since the criteria for grouping the trees in the given strata was pre-defined by their height, Figure 27 is only illustrative.

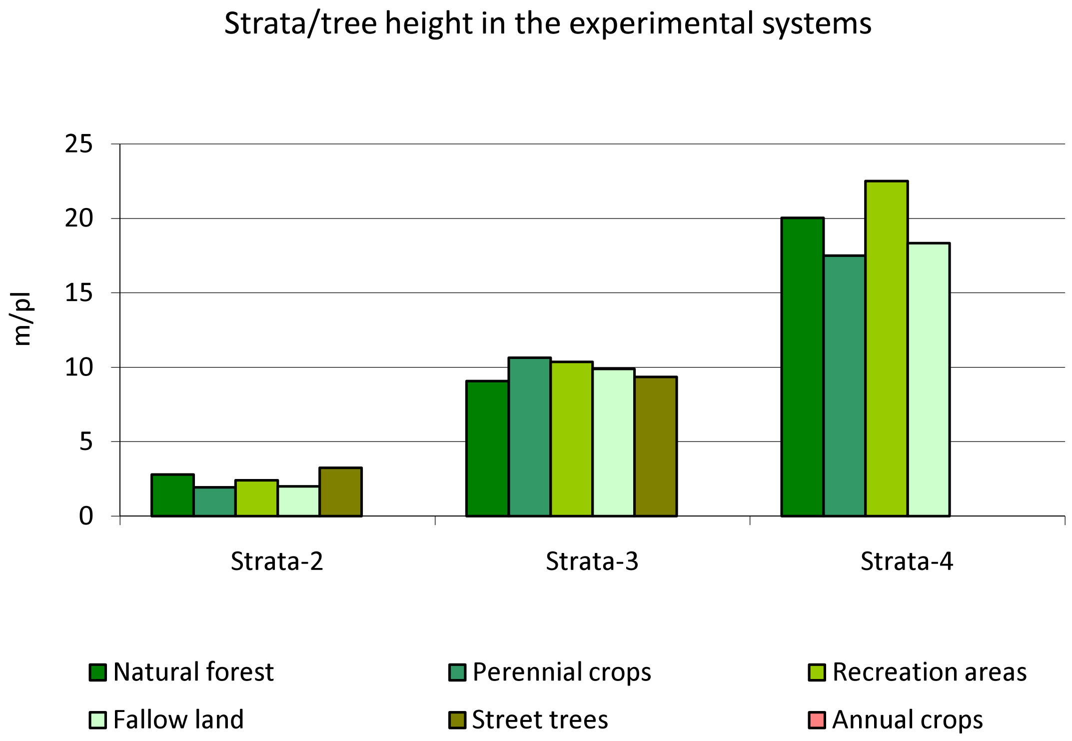


Figure 27: Mean tree height in strata 2, 3, and 4 in the experimental systems.

When the tree heights are added on one hectare and relativized to their density, the linearity mentioned above disappears what makes a comparison between the systems more objective.

If all the tree heights are added in the natural forest system they will reach a length of 8051.70 m/ha. In this system the mentioned linearity can still be observed since strata-2 accumulates 966.76 m/ha, strata-3 accumulates 2412.98 m/ha and strata-4 accumulates 4671.52 m/ha.

In the perennial crops system the strata-2 adds 272.07 m/ha, strata-3 increases a little up to 465.28 m/ha and the added length of the trees in strata-4 is reduced again to 321.13 m/ha. The total length of the added trees in this system is 1058.47 m/ha, almost ¼ of the natural forest system.

The Recreation area system shows a pattern similar to the perennial crops system but with a total accumulated length of 2303.42 m/ha (almost ½ of the natural forest system). Strata-2 adds 333.40 m/ha, strata-3 adds 1825.12 m/ha and strata-4 adds only 144.90 m/ha.

Fallow land systems start with 4.00 m (accumulated tree height) in Strata-2, 300.35 m in Strata-3 and 527.90 m in Strata-4, completing 832.26 m when all strata are added.

Since the shade trees on the streets are systematically planted in certain densities on the sidewalk, independent from their height it is no surprise that the accumulated height increases from one strata to the next. In this system the strata-2 adds 107.61 m and strata-3 adds 206.13 m. There is no strata-2, 3 and 4 in the annual crops system to be evaluated.

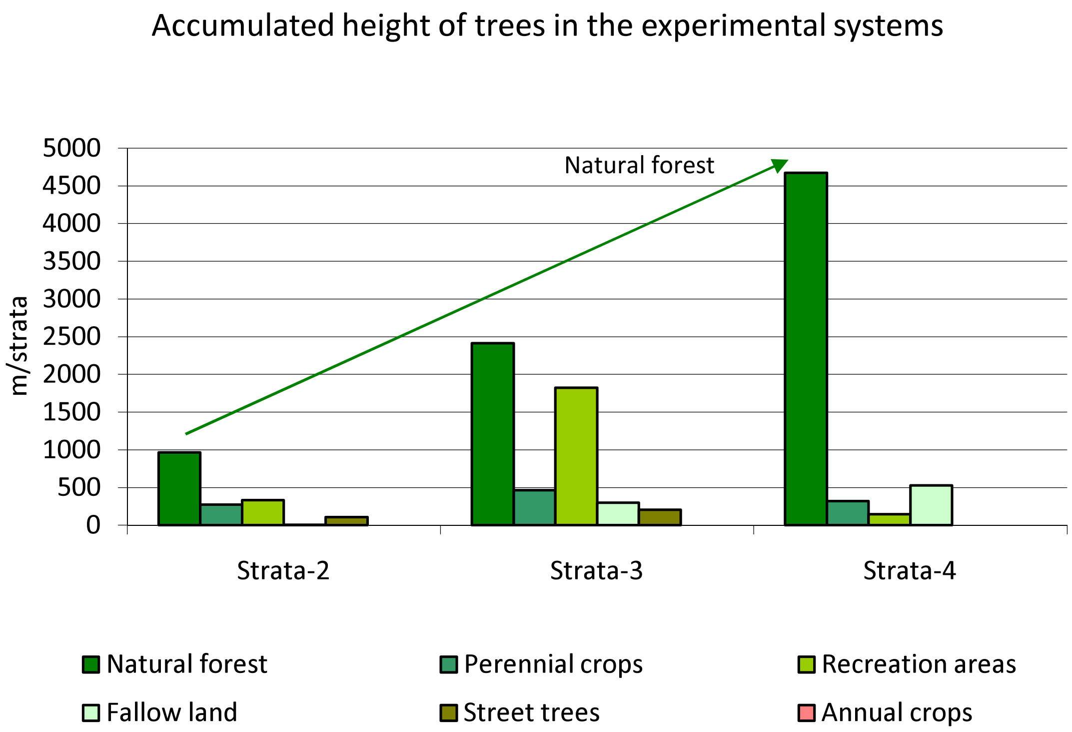


Figure 28: Accumulated height of all trees in one strata in the experimental systems.

When applying a polynomial regression to explain the different heights by the plant density, an R^2 of only 4.37 % results in a very weak relationship between those variables across the systems. Yet the P-value of less than 0.01 indicates that in fact, even if weak, there is a relationship. Higher densities tend to produce taller trees when all systems are compared.

5.1.3 Total biomass in the experimental systems

The experimental system that stores the largest quantity of dry biomass (BM) per hectare is the perennial crops system, storing a BM of 123.53 t/ha, followed by the natural forest system with 99.66 t/ha. In a second instance the fallow land, recreation areas and the street trees systems store in average 48.62 t/ha and are statistically not different from each other at a 95% confidence level (LSD). The lowest BM is stored in the annual crops system (1.79 t/ha) composed only by strata-1, the first layer in this study.

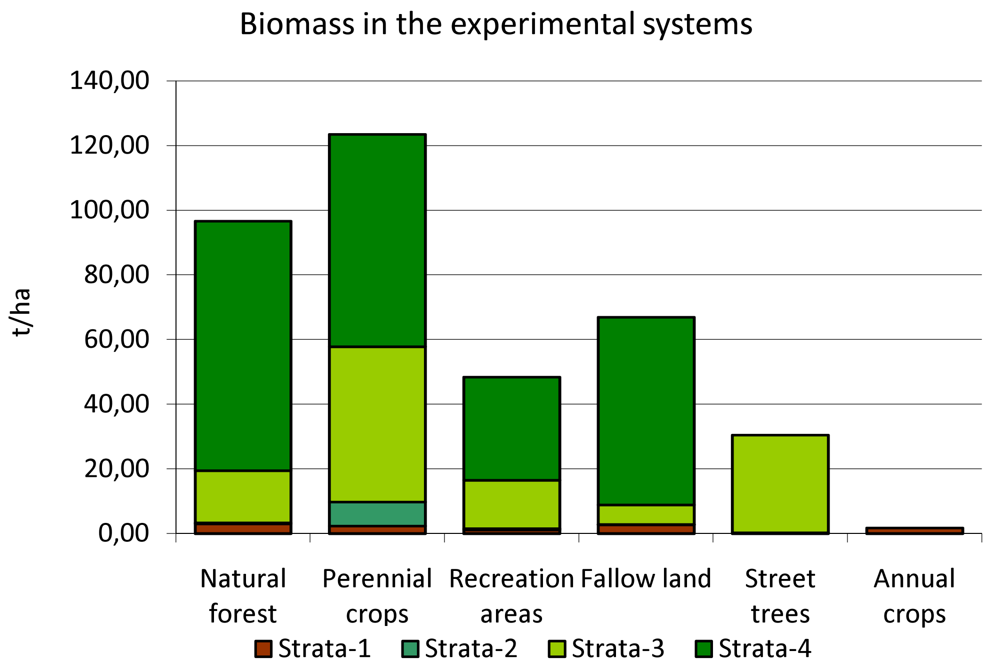
Even though it is important to note that this is the constant biomass stored. Considering that there are 7 harvest actions for the vegetables across the year and 2 harvest actions for the cassava plantations, it is important to mention the accumulated DM across the year by the intensive cultivation of these areas which is 9.51 t/ha of DM in strata-1.

The larger BM storage in the perennial crops systems compared to the natural forest systems happens in both, the strata-2 and strata-3 respectively while the lowest strata-1 and the highest strata-4 are similar and statistically not different between that systems in a 95% confidence interval (LSD).

Contrary to the perennial crops system, the recreation areas system stores statistically the same BM in strata-2 and strata-3, but a lot less (almost ½) in the lowest strata-1 and the highest strata-4.

The DM in the fallow land systems (a total of 66.95 t/ha) comes mostly from the strata-4, very tall trees conserved in the landscape, left-over's from the former original vegetation. The lower strata of this original vegetation have been cleared for agriculture and abandoned by times, therefore not replanted. The spontaneous vegetation regenerating in the lowest layer (strata-1) contributes more to the biomass storage than this layer in other systems (2.80 t/ha) and almost as much as this layer in the natural forest system (3.02 t/ha).

The shade tree systems are very simply structured systems, composed mostly by trees from strata-3 (>5 to 15 m height). Only a little part of the total BM is contributed by trees from the lower strata-2. In total this system stores 30.47 t/ha of BM.



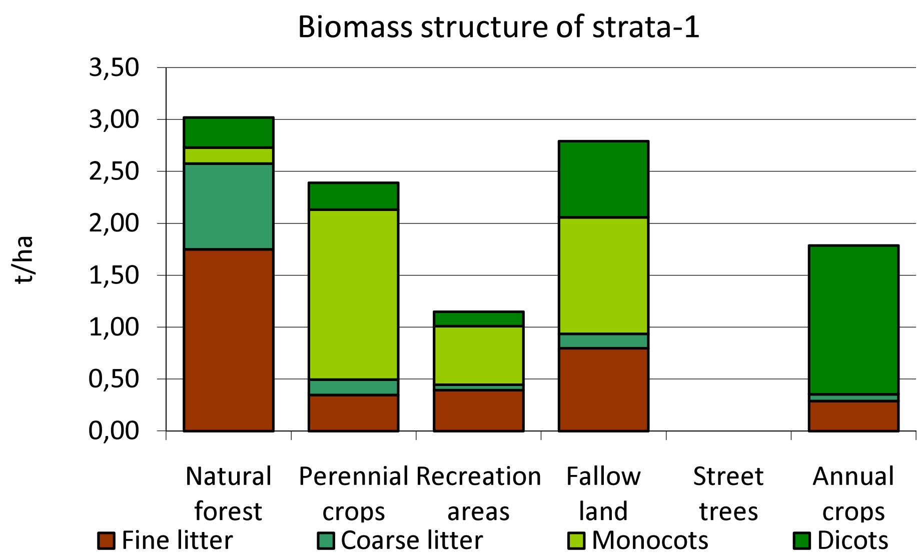
	Strata-1	Strata-2	Strata-3	Strata-4	Total
Natural forest	3.02 a	0.30 a	16.21 a	77.13 a	96.66 a
Perennial crops	2.40 a	7.41 b	48.02 b	65.70 a	123.53 a
Recreation areas	1.15 b	0.39 ab	14.99 ab	31.92 b	48.45 b
Fallow land	2.80 a	0.01 a	6.10 a	58.04 b	66.95 ab
Street trees	0.00 c	0.32 a	30.15 b	0.00 c	30.47 bc
Annual crops	1.79 b	0.00 c	0.00 c	0.00 c	1.79 c

Figure 29: Total biomass stocks per strata and experimental system. Different letters in one row are statistically different at a 95% confidence level (LSD).

Even with a statistically similar total BM in strata-1 between the natural forest, the perennial crops and the fallow land systems, the structure of this layer differs a lot. In Figure 30 it is possible to understand why.

While the natural forest system stores the largest BM of strata-1 in dead organic material (fine and coarse litter), the other systems store the largest BM in living plants. In the perennial crops system the monocots are dominant because farmers use to maintain grasses and pasture vegetation (*Brachiaria*) for fodder.

In the recreation areas the total BM in strata-1 is low because the areas are cleaned up in certain intervals, larger twigs are collected and ornamental grasses, which are dominant, are pruned and maintained short. The fallow land systems are as the name says not managed and exposed to the natural development and succession processes. Dead organic material (litter) is only lower than in the natural forest system and the BM in living plants is not as dominated by monocots like in the perennial crops and in the recreation area systems. The dicots play a more important role here, indicating more diverse vegetation in strata-1.



	Fine litter	Coarse litter	Monocots	Dicots	Total
Natural forest	1.75	0.83	0.15	0.29	3.02
Perennial crops	0.35	0.15	1.64	0.26	2.40
Recreation areas	0.40	0.05	0.56	0.14	1.15
Fallow land	0.80	0.14	1.12	0.74	2.80
Street trees	0.00	0.00	0.00	0.00	0.00
Annual crops	0.29	0.06	0.00	1.44	1.79

Figure 30: Biomass stocks and structure of strata-1 in the experimental systems.

As mentioned above, the street trees system has no strata-1 because the trees are planted along the sidewalks of the streets and the annual crops system is completely man made, in this case it is even expected that strata-1 is composed only by dicots in the living BM pool. Farmers try to optimize their harvest what means that they are mostly interested in exporting the BM in form of valuable vegetables and crops. In other words, when the produced quality is good, the residues left on the fields (fine and coarse litter) are low.

5.1.3.1 Yearly biomass production in the experimental systems

To measure the yearly BM production in the systems it would have been necessary to measure at constant intervals the litter fall using nets or other litter bags which were not possible to leave in the studied experimental systems due to security risks in the urban fringe. To compensate the data set, an approximate yearly litter fall was calculated by using measurement data from Torrico (2006) who analyzed and compared different systems in the Mata Atlantica region of Teresopolis in the state of Rio de Janeiro. In the annual crops systems the production of each crop cycle can be added across the year a considered as litter fall, even if the largest part is exported after harvest, this mass is considered as the NPP (net primary production) of this system.

Table 9: Calculation of the turnover rate and yearly litter fall in the experimental systems

	Total BM (t/ha)	Litter fall (t/ha/y)	turnover rate	Soil litter-1 (t/ha)	Soil litter-2 (t/ha)	BM exported (t/ha/y)
Natural forest	96.66	3.48	0.74	2.58	2.58	0.00
Perennial crops	123.53	4.45	0.74	0.5	3.29	2.79
Recreation areas	48.45	1.74	0.74	0.45	1.29	0.84
Fallow land	66.95	2.41	0.74	0.94	1.78	0.84
Street trees	30.47	1.10	0.74	0	0.81	0.81
Annual crops	1.79	27.94	0.74	1.79	20.68	18.89

The forest fragments in Torrico (2006) had a total above ground BM of 194.05 t/ha and produced 6.91 t/ha/y of DM (litter). Dividing the yearly litter fall by the total above ground BM, we obtain a ratio of 0.036 t of litter produced yearly by one t of above ground BM. When this ratio is applied to the total above ground BM from the experimental systems in this thesis it is possible to create an approximate analysis of the yearly litter fall (Table 10) for each system.

Table 10: Biomass stocks and fluxes in the experimental systems

	Total BM (t/ha)	Litter fall (t/ha/y)	turnover rate	Soil litter-1 (t/ha)	Soil litter-2 (t/ha)	BM exported (t/ha/y)
Natural forest	96.66	3.48	0.74	2.58	2.58	0.00
Perennial crops	123.53	4.45	0.74	0.5	3.29	2.79
Recreation areas	48.45	1.74	0.74	0.45	1.29	0.84
Fallow land	66.95	2.41	0.74	0.94	1.78	0.84
Street trees	30.47	1.10	0.74	0.00	0.81	0.81
Annual crops	1.79	27.94	0.74	1.79	20.68	18.89

Yet, the ratio created by dividing the yearly litter fall explained above by the measured soil litter in a stabilized system, in this case, using the natural forest system as a reference, shows that the yearly turnover rate of litter is 0.74 also very similar to the turnover rate of 0.78 found by Gama-Rodrigues (2007) in the Mata atlantica region of the federal state of Bahia, also in the north-eastern part of Brazil.

This means that for each t of litter lying on the soil only 0.74 t are decomposed and mineralized by soil organisms across the year. Now again, extrapolating this ratio to the studied systems it is possible to approximately calculate how much litter would have to be on the soil if the corresponding systems would be already stable (soil litter-2). The difference to the measured litter (soil litter-1) is than the Estimate of BM exported from the systems in yearly intervals.

The assumption that no BM at all is exported from the natural forest system is crucial to the calculation of the turnover rate mentioned above. As a result it is estimated that Annual crops export the highest BM in form of vegetables sold (18.89 t/ha), followed by the perennial crops system where fruits (Mango, Banana, coco-nuts) are exported for consumption (2.79 t/ha).

Interesting are the three systems that export almost the same amount of BM (recreation areas, fallow land and street trees) between 0.81 and 0.84 t/ha. The principal aspect here is that the fallow land systems have a higher litter fall than the others, almost 16% higher than in the recreation area systems and up to 37% more than in the street trees systems. This relatively lower export of BM in the fallow land systems is explained by the fact that in both, recreation area- and street tree systems active and systematically planed pruning and sweeping takes place by public maintenance services. Yet in the fallow land systems the woody parts (coarse litter) is often used by the local population for firewood, sometimes for construction purposes.

It is important to note that this yearly litter fall and the resulting estimation of exported BM is an estimation based on data from other studies. It is possible that the calculated soil litter in fallow land systems is over estimated while the same turnover rate as in the natural forest systems is used. For instance, the values in the work of Gama-Rodrigues (2007) varied from < 0.45 to > 0.95.

5.2 Biodiversity in the experimental systems

Surprisingly the species richness is the highest in the recreation area systems (Table 11). Analyzing the data from Schmidt (2007) it is possible to understand why. The Biodiversity assessment also took place in private gardens from not so poor households who like to increment their gardens with bought ornamental plants like orchids and bromelias. In this areas Schmidt (2007) found up to 106 different species, a lot more than the 27 found in the public recreation area maintained by the public services.

Yet the proportion of native species is almost half of the natural forest systems. The reason is that in recreation areas the ornamental value is the reason for its existence in this system, not the natural system dynamics like in the natural forest systems.

Table 11: Species richness in the experimental systems

Experimental system	Total sp. (nr.)	Native sp. (nr.)	Exotic sp. (nr.)	Native sp. (%)	Exotic sp. (%)
Natural forest	43	25	10	57	23
Fallow land	33	20	7	61	20
Perennial crops	24	8	16	33	67
Annual crops	20	2	18	10	90
Recreation areas	62	18	37	30	62
Street trees	7	1	6	14	86

The highest percentage of native species is found in fallow land and in natural forest systems (61 and 57 % respectively). This shows that the penetration of well adapted exotic species is still very high when forest fragments are left without any planed management with the aim to regenerate to the original state.

The most important exotic species that grow in these systems are Mango trees (*Mangifera indica*), Jack fruit trees (*Artocarpus heterophyllus*) and Avocado trees (*Persea americana*).

5.3 Three-dimensional structure of the land use systems

The above ground volume occupied by a uniform stand type is called V_{eco} (Eco-volume) and is expressed in m³. The height of the original and native vegetation in an area shows the potential V_{pot}. In this case the natural forest system was used as a reference for the V_{pot} to make all other systems comparable between each other.

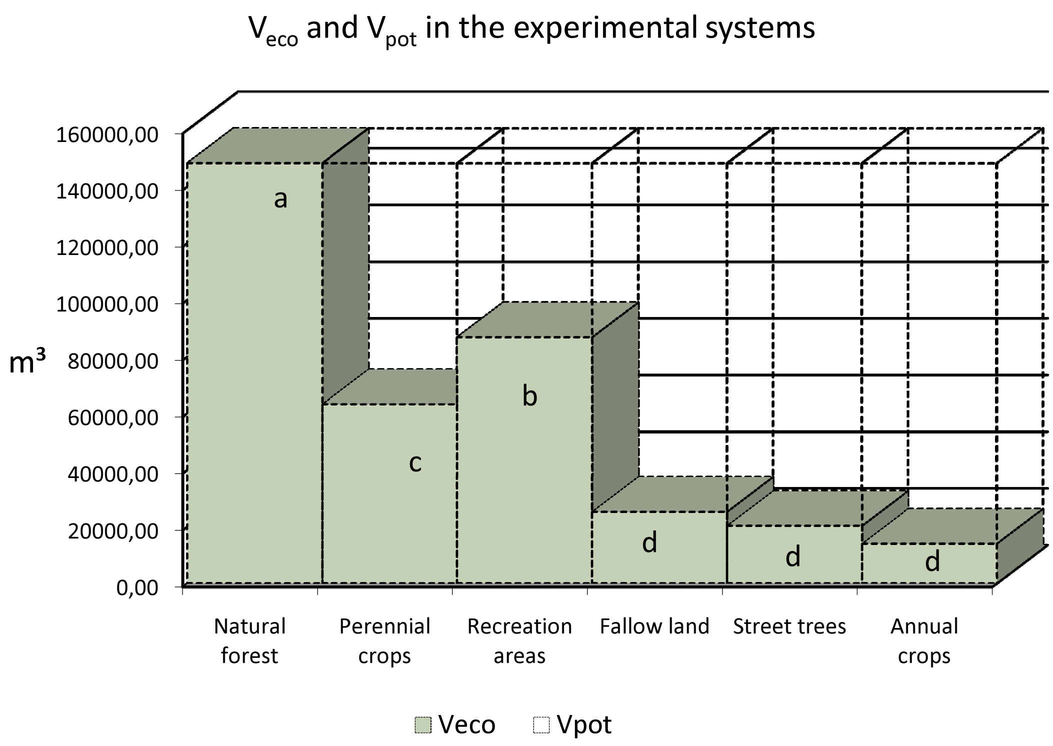


Figure 31: Eco volume (V_{eco}) and potential eco volume (V_{pot}) in the experimental systems.

The V_{eco} in the Natural forest system is the highest (148253 m³/ha) and is considered as the V_{pot} for the other systems as a reference. If the V_{eco} is expressed in percentage of the V_{pot}, the recreation area systems occupy 58.56 % of the V_{pot}, the highest among the experimental systems, followed by the perennial crops systems that occupy 42.6 % of the V_{pot}. The Fallow land, street trees and annual crops systems use less than 18 % of their potential volume.

The next step is to understand how the V_{eco} from each system differs from others in its density. To keep the three dimensional scales this will be done by comparing the bio-volume (V_{bio}) of the systems. V_{bio}, as mentioned in chapter 4.5.3, is the volume occupied by each individual tree and the V_{bio} of a stand is the sum of all V_{bio} in a certain area. The percentage of the V_{eco} occupied by the V_{bio} of a system is called the "crowding intensity" or short: "C_i".

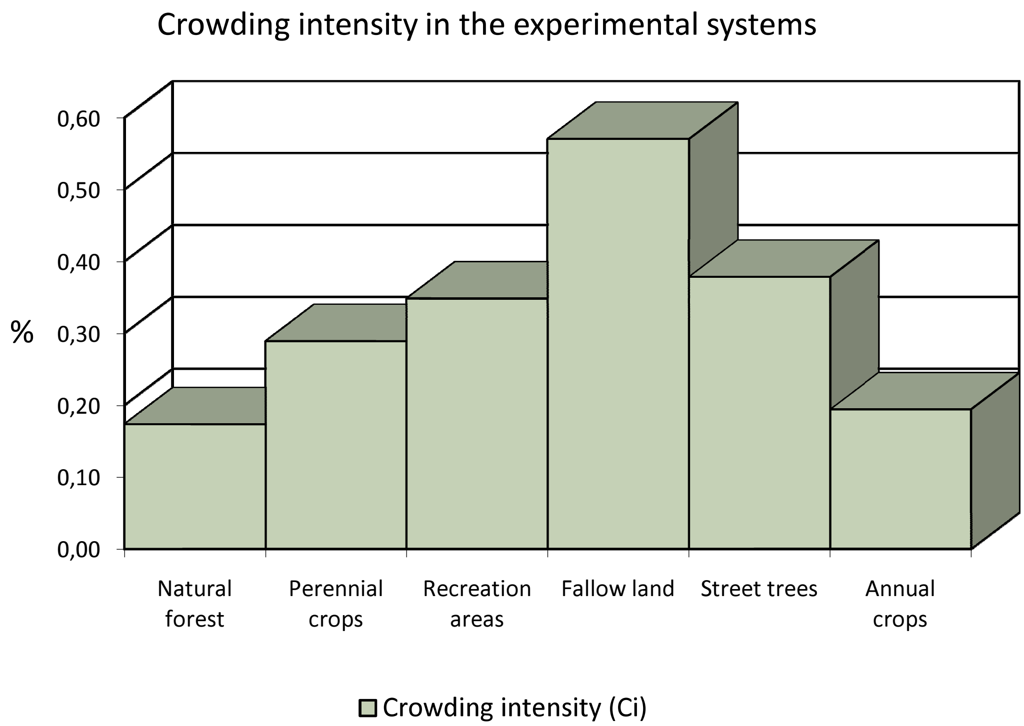


Figure 32: Crowding intensity (C_i) in the experimental systems expressed in percentage.

When comparing Figure 31 to Figure 32 it looks like that there is a tendency of systems with a low V_{eco} to crowd more intensively but no regression analysis could confirm that. Even though the system with the highest C_i is the fallow land system and the lowest is the natural forest system, both not actively managed and left in natural conditions representing two different development stages of a natural succession process, what confirms that in nature, systems tend to colonize a three-dimensional space.

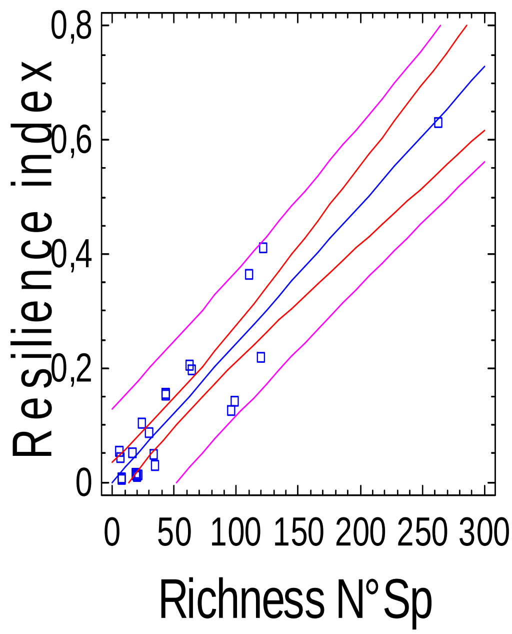
The most important indicator in this three-dimensional system analysis is the resilience (R_i) expressed in percentage of V_{pot} that is occupied by the actual V_{bio}. The more resilient a system is, the more it can resist to external disturbances and get back to its original estate.

In Figure 19 Torrico (2006) could confirm a strong linear relationship between "R_i" and the species richness in different land use systems around the world. When a linear regression is applied to the experimental systems in this research the relation between Ci and richness could be confirmed by the equation:

Resilience index = -0.0113852 + 0.00334556*Richness

This equation shows a correlation coefficient of 0.85 and explains 73.09 % of the variability (R^2). Now the Figure 19 from Torrico could be completed by the land use systems from Recife (in bold letters):

System	Resilience	Richness
Grass system	0.005	8
Citrus	0.006	8
Annual crops-Recife-Brazil	**0.009**	**20**
Fruit Vegetables	0.012	19
Mixed Vegetables	0.013	21
Leaf Vegetables	0.014	19
Sylvopastoral	0.029	34
Street trees-Recife-Brazil	**0.044**	**7**
Fallow land-Recife-Brazil	**0.047**	**33**
CaatingaTeresina-Brazil	0.052	16
Water plants	0.054	6
Regeneration forest (3y)	0.088	30
Perennial crops-Recife-Brazil	**0.102**	**24**
Ecological	0.124	96
Coffee Chiapas-Mexico	0.142	99
Forest Uganda	0.154	43
Natural forest-Recife-Brazil	**0.156**	**43**
Forest fragment Chiapas	0.198	64
Recreation areas-Recife-Brazil	**0.206**	**62**
Cocoa Agro-forest	0.220	120
Fragments Mata Atlantica	0.365	110
Coffee Nordeste-Brazil	0.411	122
Forest Mata Atlantica	0.630	263



Explanation: The output shows the results of fitting a linear model to describe the relationship between resilience index and richness. The equation of the fitted model is resilience index = 0.0000908416 + 0.00243008*Richness. Correlation coefficient = 0.928. Rsquared = 86.1 percent. Source: Torrico (2006) and completed (bold letters) by the author.

Figure 33: Simple regression - Resilience index vs. richness.

Interesting is the recreation areas system that gets really close to some forest fragments like in Chiapas (Mexico). This leads to conclude that these systems are closer to their natural profile than even the natural forest systems (which are in fact forest fragments).

Yet, there is one important point to maintain the question mark on this observation. The species richness found in recreation area systems is composed by only 30 % (Table 11) of native species (total of 18) while the natural forest systems are composed by 57 % of native species (total of 25). Even the fallow land systems are composed by 20 different native species representing 61 % of the total. The importance of the species origin in terms of a quality indicator of a system and its ability to recover the natural structures and dynamics is not valued here.

5.4 Carbon and energy stocks and fluxes

The comparison of the carbon stock, production and its export out of the respective land use system can help decision makers to plan and incentive the development of certain land uses during a controlled urbanization process.

Table 12 shows that the highest carbon is stored by the perennial crops system (61.77 t/ha), yet the highest fixation rate is done by the annual crops system (10.34 t/ha/y) from which the largest part (9.44 t/ha, almost 91%) are exported in the form of tradable goods.

The annual crops system fixes the highest amount of carbon per year but in terms of climate change and land use change the transformation of one hectare of any other system into the annual crops system would emit to the atmosphere between 14 and 61 t of carbon that would be kept stored in the alternative biomass.

Table 12: Carbon and energy stocks and fluxes in the experimental systems

	Carbon stocked (t/ha)	Carbon fixed (t/ha/y)	Carbon exported (t/ha/y)	Energy stocked (J/ha)	Energy produced (J/ha/y)	Energy exported (J/ha/y)
Natural forest	48.33	1.29	0.00	2.20E+06	5.88E+04	0.00E+00
Perennial crops	61.77	1.65	1.40	2.82E+06	7.50E+04	6.36E+04
Recreation areas	24.23	0.65	0.42	1.10E+06	2.94E+04	1.92E+04
Fallow land	33.48	0.89	0.42	1.53E+06	4.07E+04	1.92E+04
Street trees	15.24	0.41	0.41	6.95E+05	1.85E+04	1.85E+04
Annual crops	0.90	10.34	9.44	9.67E+05	1.12E+07	1.02E+07

Interpreting this data, this would mean that if the land that actually is covered by annual crops would be abandoned and kept fallow, 33 more tons of carbon per hectare could be stored in the above ground biomass, thus reducing atmospheric carbon. The huge amount of carbon fixed yearly cannot be considered as a sink because it will be consumed in other system and get back to the atmosphere.

Yet, this high fixation rates are related to the intensive rotation and harvest cycles that are of direct economic interest of the farmer. Different from the perennial crops that store the highest amount of carbon but only export (in this case the production of eatable fruits) 15% from the mass that is traded by the annual crops.

The estimation of the cooling potential of the experimental systems is based on productive (C_{fs} and V_{ecos} vs. EVT and confinement factor) and structural (C_{is} and H_{ecos} vs. shade density and distribution).

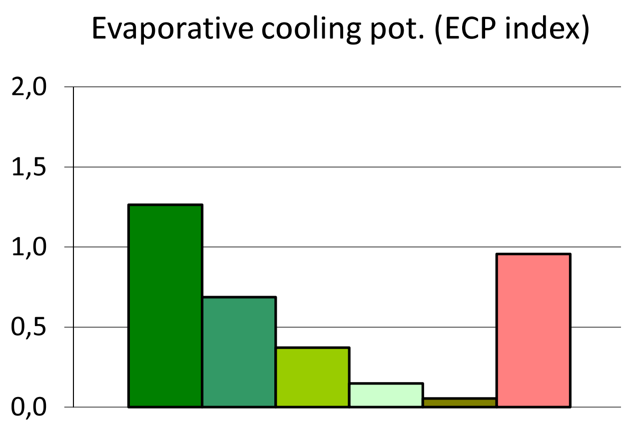


Figure 34: Evaporative cooling potential in the experimental systems.

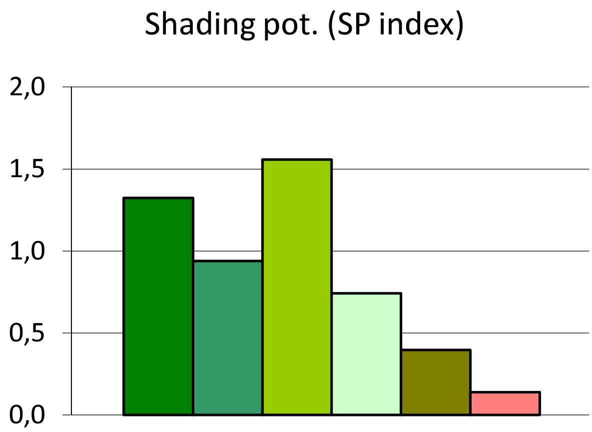


Figure 35: Shading potential in the experimental systems.

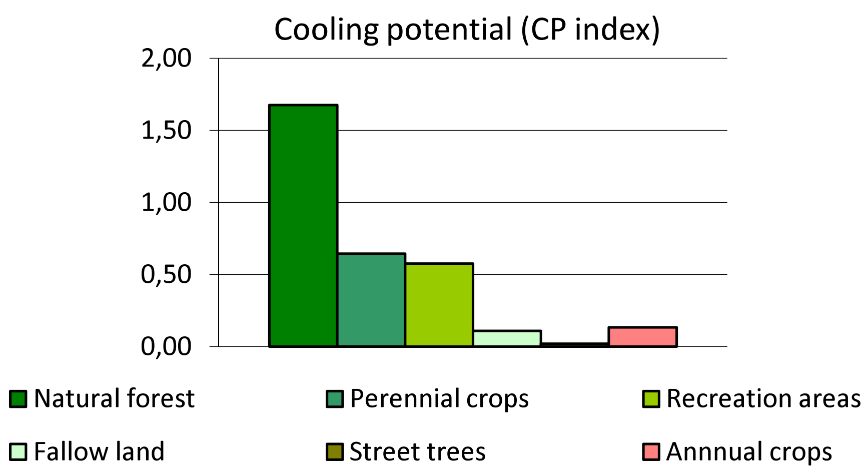


Figure 36: Cooling potential in the experimental systems estimated though productive and structural parameters.

The CP_i in the natural forest system is almost three times higher than in the perennial crops and recreation area systems due to the high confinement factor presumed to be a function of V_{eco}. The cooling effect resulting from high transpiration rates (function of the C_{fs} in t/ha/y) in the annual crop system is off-set by the low V_{eco} that increases the dispersion of the cooled air to the atmosphere, reducing the confinement factor. The lowest CP_i is found in the street tree system in which all factors are the lowest due to the sparse distribution of trees (Figure 24) that results in a low EVT rate and a low shade density on a ha basis. Those cannot be compensated by the high DBH of the individuals (Figure 25) which is a function of C_{is}.

5.5 Critical outlook

The experimental systems analyzed represent a large variety of land use systems found in urban areas, from natural forest systems usually representing the untouched nature, through agriculture formed by socio-economic demands and to street trees and recreation areas representing very urban interests like socialization, shade and relaxing.

Generally it can be concluded that fallow land and natural forest systems tend to have a similar structure due to the fact that they are not managed actively. Both systems are formed by the natural succession process being the fallow land system a very early stage of a regenerating natural forest system. In the first one, high amounts of biomass concentrate in the herbaceous vegetation of strata-1 while in the second one biomass is distributed across all strata with a very high plant density that is reduced while trees get higher and basal areas increase. In both systems the increasing plant height is accompanied by an increasing total basal area.

The difference is that the low plant density in the higher layers of the fallow land system are compensated by higher basal areas per plant while the natural forest system have a much higher plant density with smaller basal areas per plant. While the natural forest systems have a very high V_{eco} (Figure 31) and the fallow land systems a very low one, the C_i behaves in the opposed direction (Figure 32). One could question how an earlier development stage (fallow land system) can have larger basal areas per tree than a later development stage (natural forest).

The reason for that is that the fallow land areas once were covered by forests that were cleared for agriculture and later for building purposes and some large trees have been left, for example *Eucalyptus citriodora Hook* (Schmidt 2007), a residue from a former plantation. Most of the areas are still cleared from time to time to keep their market value for building purposes. Thus, the natural succession process is kept artificially at a very initial development stage.

Perennial crops and recreation areas are actively managed by pruning and harvest to fulfill different specific functions. In both cases the tendency of the systems is to store the highest amounts of biomass (consequently carbon) without affecting the purpose of their existence. In the first case this is principally the production of fruits and in the second case the supply of recreation, esthetics and comfort for urban settlers. In these systems the intermediate plant densities and heights are compensated by larger basal areas of trees that are actively managed and protected. They are not exposed to the pressure of the succession process which is offset by pruning and harvest practices. That why there is no representative further biomass increase to be expected.

In both experimental systems the excessive biomass is only partly exported in the form of fruits (perennial crops system) and large branches from pruning and cut grass (recreation area system). Interesting is the fact that in the three dimensional approach, both systems show relatively high V_{eco} (Figure 31) but with a similar C_i (Figure 32) if compared to the other actively managed systems. This information together with the highest resilience indexes in these systems (Figure 33) indicates a development stage closer to the agroclimax than the annual crops and the street tree systems. The term agro climax was first suggested by (Janssens et al. 2006) and can be defined as:

"The state of agricultural systems in which sustainability components reach a balance, in function of a production system combining environmental and socio-economic factors within a region" The energy balance inside the system reaches high levels of efficiency, renewability and transformation. These systems have high capacity to harbor, to use and to manage Agro-biodiversity and finally they present a wide elasticity to pass to natural systems. This balance is a function of the production system, environmental and socioeconomic factors of each region (Torrico 2006).

In this context, natural forest and fallow land systems tend to reach the Eco-climax, where social-economical implications do not define their structure and composition, only their existence (natural forest systems) or not (fallow land systems cleared from time to time).

The most simplified structure is found in the street tree systems and in the annual crop systems. They are both limited to occupy a restricted layer of the open space. The street trees occupy only strata-2 and 3 and their functions are reduced to provide shade on the sidewalks. To fulfill this function they need to correspond certain geometric patterns not only for esthetic reasons but also due to the lack of space available to develop. For example they should not have more than 5 m height when planted under power lines. As a result the diversity of only 7 species is very low and the complete pruning material is exported from the system to keep sidewalks (which are impermeabilized) clean.

The annual crops occupy only strata-1 and store the lowest carbon but their function is to provide income. They are managed in intensively rotating systems that provide up to seven harvests per year. They have the highest carbon fixation rates (10.34 t/ha/y) but also the highest exports in form of tradable goods.

The estimated cooling potential in the natural forest system is the highest. In the methodology applied to calculate the ECP based on yearly carbon fixation, it is important to note that the natural forest system is assumed to have a NPP = GPP while in fact these systems are not completely developed forest fragments, thus presenting a not evaluated but expected potential biomass increase.

For the interpretation of the results this means that the ECP in this system could be even higher. The SP in the recreation area systems is the highest, producing a dense shade due to the relatively high C_i and in a sparse above ground volume delimited by its H_{eco}. In this sense this system best fulfills its function of providing a cooled and spacious microclimate for recreation and relaxing.

6 CASE STUDIES

In this chapter the six selected cases will be presented. Each case represents one typical neighborhood in the experimental area.

6.1 Area I: Estrada dos macacos

6.1.1 General description

Located at the north fringe of the “Parque Dois Irmaos” in Recife, the Estrada dos macacos (Monkey Street) was colonized around the years 1950 and 1960. Like many parts in the peri-urban fringe of Recife, once this area belonged to big and important farmers who produced sugar from sugar cane (Töpfer 2007).

Figure 37: Estrada dos macacos.

From time to time the workers started to occupy parts of this land and started to become producers. Nevertheless they occupied unproductive and less fertile land (personal interviews). After many years of fights between the farmers who legally own the land and the former land workers which occupied the land by force, many of the cases are still undefined. In many cases the Farmers donated the land to the workers, in others there are still legal implications being discussed (personal Interviews).

One particularity here is the physical isolation. At the south, the protected area of the “Parque Dois Irmaos” permits no direct access to the city. Actually the new generations are not land workers anymore, they have to go for a one hour foot and bus trip to reach the city for their jobs.

Even if the areas had been occupied with the intention to be turned productive from the agricultural point of view, larger plots have been negotiated and fragmented along time.

The children of the original land workers grown up and constructed their own housings besides their parents. Since the surrounding areas are strictly controlled, the building of new houses cannot expand into new areas what leads to an intensification of the former occupied areas. It looks a little bit like an urban fragment surrounded by forests and fallow lands.

Table 13: Social profile of area-I (Estrada dos macacos)

Estrada dos macacos			
Nr. of households interviewed:		26	
Educational level of the adults:			
	illiterate:	27	% of the adults
	8th grade (primary level) incomplete:	46	% of the adults
	11th grade (secondary level) incomplete:	12	% of the adults
	11th grade complete:	8	% of the adults
	High-school level complete:	8	% of the adults
Nr. of people/household:		4	
Nr. of Children/household (under 16 y):		1.5	
Household income:		973.08	BRL/month
Individual income:		240.95	BRL/month
Land tenure:			
	formal:	27	% of the households
	informal:	31	% of the households
	undefined:	42	% of the households
Years passed since migration			
	<10 y:	12	% of the households
	10 to 20 y:	31	% of the households
	>20 y:	58	% of the households
Origin of the settlers			
	urban:	31	% of the settlers
	rural:	35	% of the settlers
	undefined:	35	% of the settlers
Perception of life-quality changes by the leaders			
	it got better:	65	% of the leaders
	it got worse:	4	% of the leaders
	kept unchanged:	31	% of the leaders
Perception of criminality by the leaders			
	low:	50	% of the leaders
	medium:	50	% of the leaders
	high:	0	% of the leaders
	very high:	0	% of the leaders
Health problems (at least 1 person) in households			
	no:	77	% of the households
	yes:	23	% of the households
	Predominant health problem:	Hypertension (HTN)	

6.1.2 Land use structure and its implications

In area-I (Estrada dos macacos) 26 households were interviewed which in total occupy an area of 18.45 ha. The individual households have a mean area of 0.71 ha what is almost half of the total mean across all areas of this study (1.40 ha). Yet, and this is important for all following areas, this mean value is high due to the fact that in many cases the land tenure is informal what gives settlers the possibility to advance with their gardens and plantations into the neighboring areas when they are not occupied or being used yet. The large plots do not correspond anyhow to the financial power of the stakeholders and their participation on (formal) real estate markets.

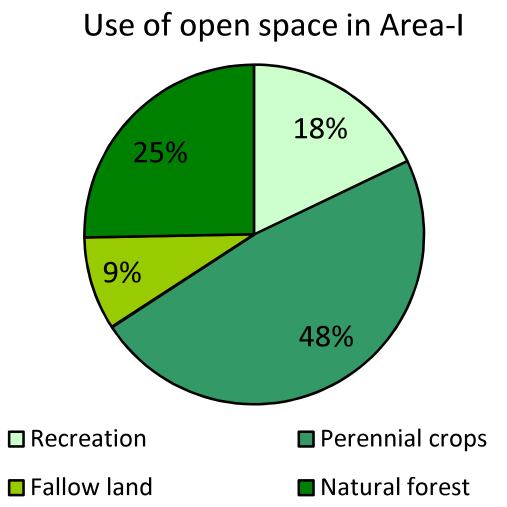


Figure 38: Importance of different land uses in area-I.

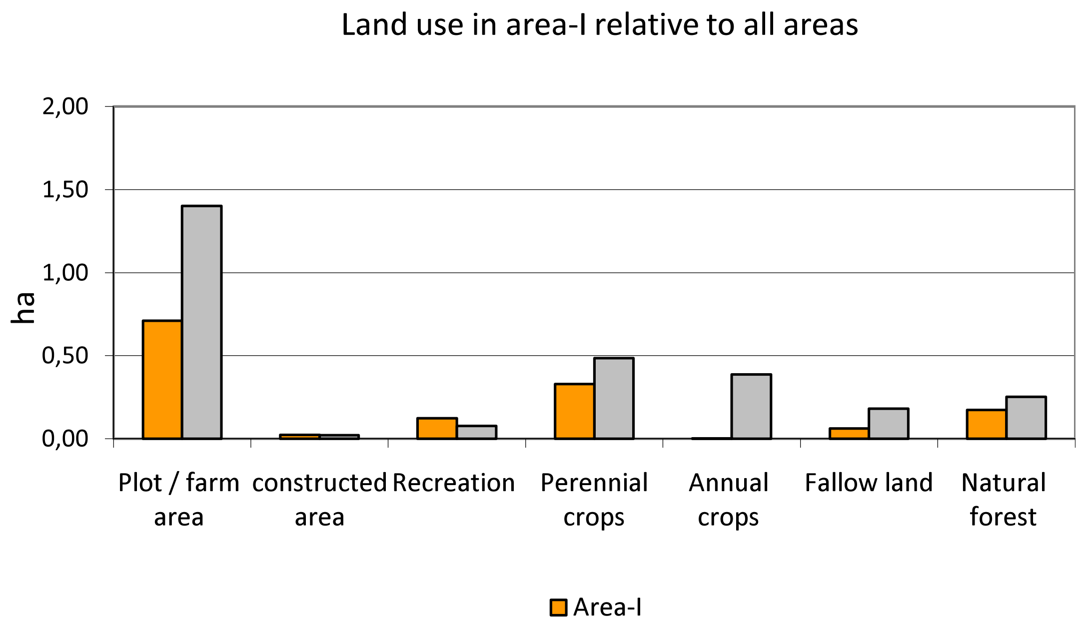


Figure 39: Comparison of land uses in typical household/farms of the "Estrada dos macacos" (area-I).

Even with smaller areas, the people use a part for recreation purposes, building their own (public/private-) recreation areas to meet with neighbors in the shade, enjoy community events and make churrasco (typical form of barbecue) (Figure 38).

Even though, the most important use of open space is the planting of some perennial crops, like small banana-, mango-, coco nut- and other fruit plantations that contribute to the subsistence. Like mentioned in the general description the new generations are not willing to be producers and look for jobs in the city what in the other hand is the reason for no annual crops in these areas.

The closeness to the protected area of the “Parque Dois Irmaos” also contributes a little to the ecological consciousness of the settlers which preserve natural forest fragments when possible. The administration of the national park is interested in involving the surrounding communities in different education projects specially the children, to prevent illegal hunting’s in its forests. Almost 30% of each plot is kept in its natural estate.

Ground sealing by constructions is relatively low with 20% of the occupied area. Yet, this number can quickly be doubled or tripled as soon the next generation constructs one more house besides the parent’s house due to the financial limitation of buying new land in other place.

This area shows the urbanization where the rural turns into urban driven by spontaneous non-planed processes which are retarded by its geographical (bordered by the protected area) and infrastructural (accessibility) isolation.

6.1.3 Use of space, carbon stocks and resilience index

The space occupied by the vegetation (V_{eco}) in area-I, considering the different land use systems and the not vegetated space (in this case the space occupied by buildings), is 36.88 % of the potential eco volume (V_{pot}) that could be occupied if the whole area was covered by the natural forest system. This is still more than the mean across all interviewed households (27.87 %).

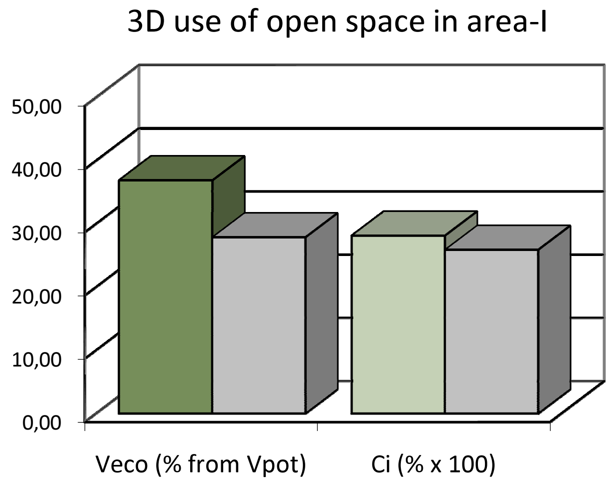


Figure 40: Three dimensional use of open space in area-I compared to the mean of all areas.

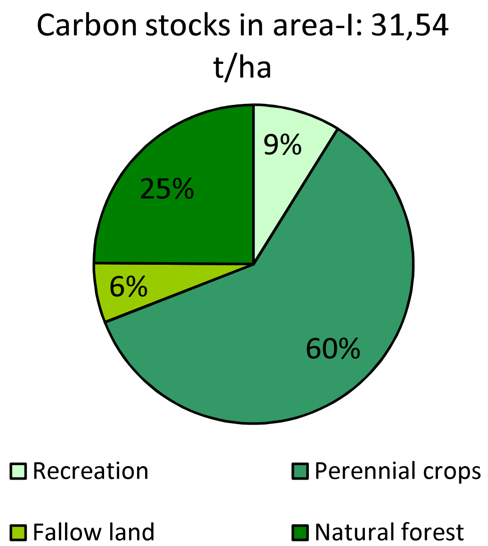


Figure 41: Importance of different carbon pools in area-I.

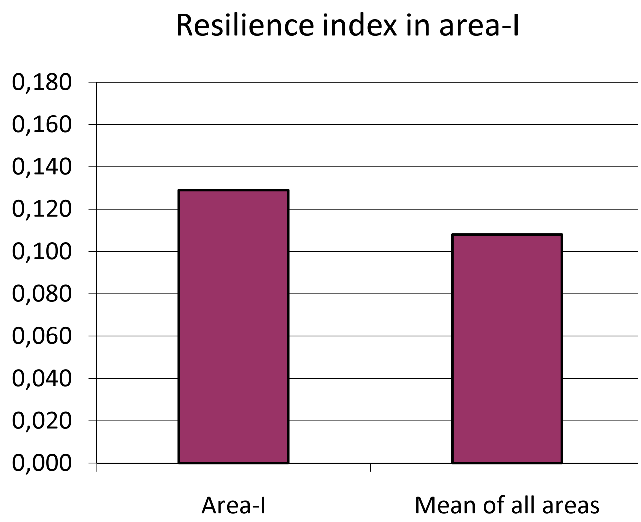


Figure 42: Resilience index of area-I compared to the mean of all areas.

Also the crowding intensity (C_i) (here expressed in %) is a little higher than the mean (0.28 and 0.25 % respectively).

In the "estrada dos macacos" 31.54 t of carbon are stored in each ha occupied by single households. The largest part (60%) is stored by perennial crops systems while forest fragments hold the second position (25 %) of the most important carbon pools. Each household stores 22.38 t of carbon in its available open spaces and 5.60 t / inhabitant.

Interesting is also the resilience of this open spaces in area-I of 0.129 (20 % above the mean of all interviewed households) what would rank the ability of this area to restore its original conditions close to the ecological farming systems of Torrico (2006) (Figure 42) even with a part of the area being used for housings with no vegetation at all.

6.2 Area II: Assentamento Macacos e Pedreiros

6.2.1 General description

Figure 43: Assentamento macacos e pedreiros.

The assentamento Macacos e Pedreiros is situated on the peri-urban northwestern fringe of Recife, split up between the municipalities of Recife and Camaragibe. It has not yet been included into the built up area of the two cities and has thus maintained many of its rural characteristics. The area has been cultivated for at least sixty years, with manioc being the most important product. Besides potatoes, yam, coconut, banana, and during the season also corn and beans are grown. There are also many old fruit trees, but due to their age the productivity is not very high. Many farmers raise chicken, goats, pigs, cows (also for milk) or horses.

Previously many of the products were sold to the neighboring settlements and to Recife. With the changes of retailing structures, away from small-scale local networks to national and international supermarket chains and industrialized production, the market access has worsened considerably for most of the small producers. Especially the deficient transport infrastructure poses enormous problems to the farmers who want to sell their products. Most roads are unpaved, eroded and impassable by car during bad weather. Even the hawkers provide their services only in part of the area. Coconuts are sold for 0.30 Reais in the Assentamento, and even for this price most hawkers don't come there to buy them, even when they could resell them in the central parts of Recife and in the beach areas for 1.50 Reais. Therefore agriculture has declined considerably throughout the Assentamento, most of the small farmers producing only little more than for their subsistence.

Table 14: Social profile of area-II (Assentamento macacos e pedreiros)

Assentamento macacos e pedreiros			
Nr. of households interviewed:		22	
Educational level of the adults:			
	illiterate:	18	% of the adults
	8th grade (primary level) incomplete:	32	% of the adults
	11th grade (secondary level) incomplete:	41	% of the adults
	11th grade complete:	9	% of the adults
	High-school level complete:	0	% of the adults
Nr. of people/household:		6	
Nr. of Children/household (under 16 y):		3.4	
Household income:		733.64	BRL/month
Individual income:		115.29	BRL/month
Land tenure:			
	formal:	0	% of the households
	informal:	95	% of the households
	undefined:	5	% of the households
Years passed since migration			
	<10 y:	0	% of the households
	10 to 20 y:	9	% of the households
	>20 y:	91	% of the households
Origin of the settlers			
	urban:	18	% of the settlers
	rural:	82	% of the settlers
	undefined:	0	% of the settlers
Perception of life-quality changes by the leaders			
	it got better:	86	% of the leaders
	it got worse:	0	% of the leaders
	kept unchanged:	14	% of the leaders
Perception of criminality by the leaders			
	low:	14	% of the leaders
	medium:	77	% of the leaders
	high:	5	% of the leaders
	very high:	5	% of the leaders
Health problems (at least 1 person) in households			
	no:	32	% of the households
	yes:	68	% of the households
	Predominant health problem:	Hypertension (HTN), diabetes	

The situation is aggravated by the unsolved land tenure of the Assentamento. The lawsuit of the former land owners against their expropriation through the INCRA (National Institute for Colonization and Agrarian Reform) has been pending with court for the last eight years. During this time the small farmers could not apply for technical assistance from public institutions, nor could they assume a mortgage on their land in order to apply for a credit. Of course like in the other areas mentioned here, the very low educational levels would be another problem despite the land tenure to develop the area into profitable agriculture. This lack of financial resources has made modernization and investment impossible for most producers, prompting the younger generation to look for work in town rather than to continue working in agriculture.

Only some farmers have succeeded in producing profitably: these are the ones that live closer to the main road and have specialized in certain areas, such as dairy or rearing fish and shrimp in ponds. In these cases, the children continue to work in agriculture.

6.2.2 Land use structure and its implications

The "Assentamento Macacos e Pedreiros" holds the most rural characteristics of all areas analyzed in this study. With a better topography and no direct space limitations such as the "Parque dois irmaos" for the area-I, here the infrastructural access is given by public transport systems and partially the streets are paved.

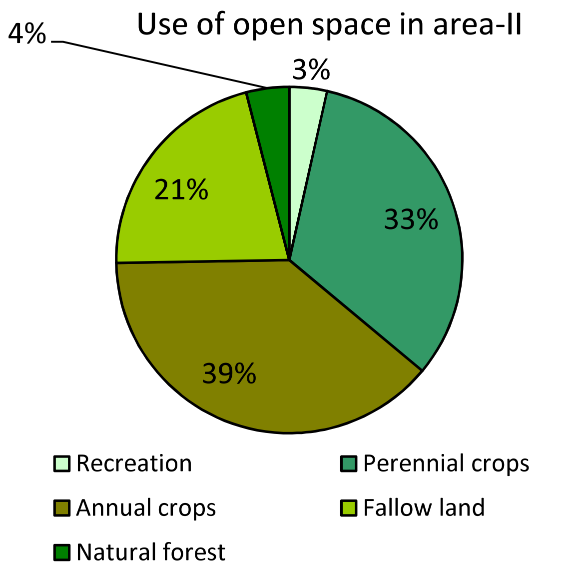


Figure 44: Importance of different land uses in area-II.

One would think that these are ideal conditions for an uncontrolled urbanization process. Actually the more productive area maintained the interest of the settlers of keeping the agricultural activity. Defending this interests the small farmers got better organized since the beginning of the occupation and founded the "Associacao de agricultores de Camaragibe", an association of about 120 small farmers that has a relative good bargaining position in respect to the land tenure issues with the INCRA (National Institute for Colonization and Agrarian Reform). The farmers are registered as rural workers and so they can benefit from some social security like a rent after the age of 65 is reached.

To keep the land with its rural characteristics and producing crops predominantly is one of the major conditions imposed to the settlers to formalize the property rights in future. At the other hand, settlers know that with the land formalized, they will have to pay taxes on the land. One of the issues being discussed is if these taxes will be oriented to rural or to urban land. This is a typical conflict where the definition "peri-urban area" seems to be useless.

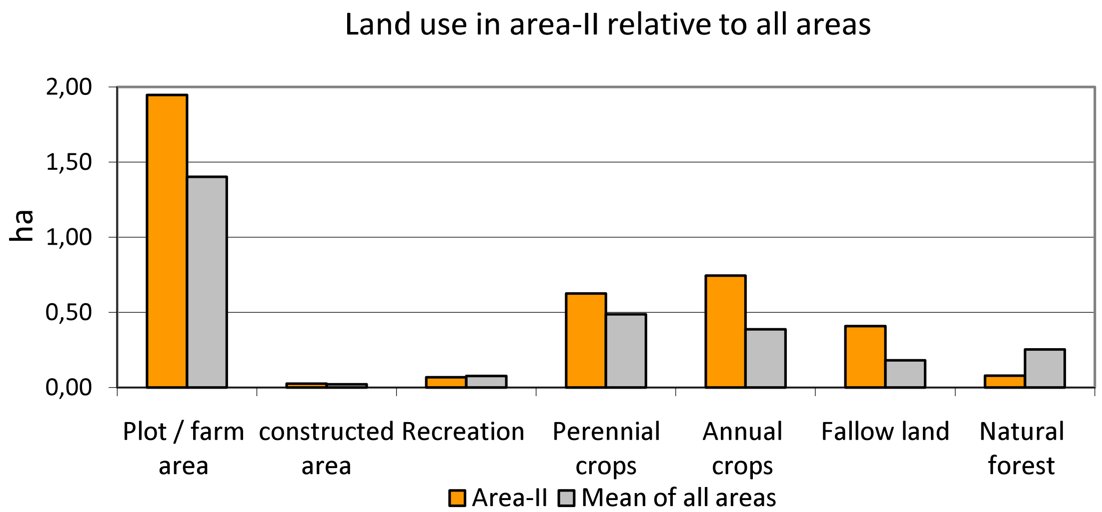


Figure 45: Comparison of land uses in typical household/farm of the "Assentamento Macacos e Pedreiros" (area-II).

In total 42.80 ha are occupied by the 22 households/farms interviewed. The mean size is of 1.95 ha and the largest of all areas and almost 75 % of that area is agriculturally used producing perennial and annual crops and vegetables. Fallow land is also twice as much as in the mean of all areas but considering the large plots, they represent less than 20 % of the total area. Fallow land is predominantly grass land and is used spontaneously for fodder by the farmers that have cows or horses.

For how long this rural characteristics will be maintained after the formalization takes place uncertain but already now it is possible to see that 50 % more people living in each household (6, against 4 in area-I) reflects in a 50 % higher ground sealing by the construction of houses (300 m² against 200 m² in area-I).

With a very low income per household coming predominantly from the agricultural activity it will be necessary to implement extension services and financial possibilities to make agriculture more interesting for the upcoming generations.

6.2.3 Use of space, carbon stocks and resilience index

The relatively large area (21 %) of fallow land and the only 4 % of natural forest reduce the overall V_{eco} of this area to 26.75 % of the V_{pot}. Yet this is close to the mean values of all interviewed households due to the fact that buildings do not reduce the vegetated space, since the individual plots are very large (1.95 ha/plot). Although the C_i is almost 15 % lower than the mean because 38 % of the area is planted with annual crops that have a very low C_i (only 0.19 %).

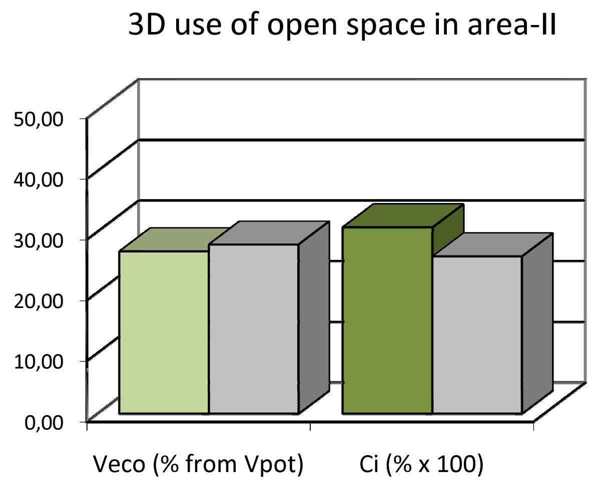


Figure 46: Three dimensional use of open space in area-II compared to the mean of all areas.

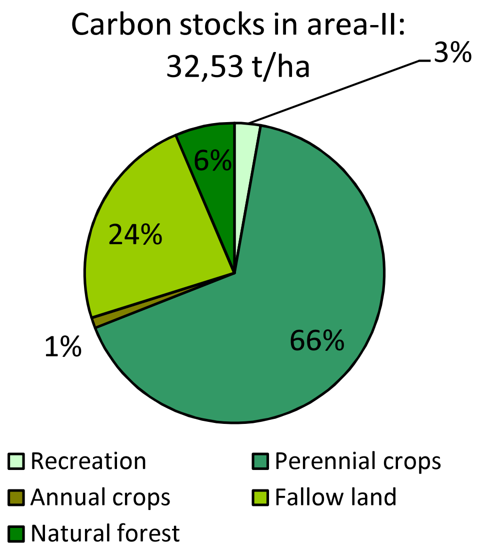


Figure 47: Importance of different carbon pools in area-II.

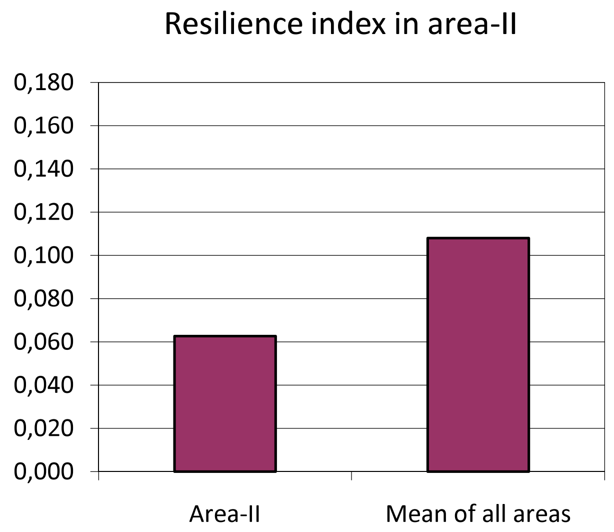


Figure 48: Resilience index of area-II compared to the mean of all areas.

Area-II stores even a ton more than area-I (32.53 and 31.54 respectively). Also here the largest pool is the perennial crops system (67 %) but the fallow land system is responsible for 23 %, differently from area-I where the natural forest system takes this position.

The rural characteristics and the larger plots explain the huge storage of 63.30 t of carbon per household. Transferred to the population density this means 10.55 t per inhabitant.

Even with these amounts of carbon stored in the open spaces of this area, the resilience index calculated is of only 0.063, almost 60 % from the mean of all interviewed households (Figure 48). This is explained by the little amount of area dedicated to recreation areas and the only 4 % of the area covered by the natural forest system, both which would contribute to increase this value (Figure 44).

6.3 Area III: Apipucos

6.3.1 General description

Apipucos is located south from the protected areas of the "Parque Dois Irmaos" and still 9 km away from the center of Recife. While the other regions still have very rural aspects and are located in the peri urban fringe, in the transition between rural and urban, Apipucos is located already in the city.

Figure 49: Apipucos.

Apipucos was nominated a national Heritage due to its preserved architecture from colonial times that represents almost ¼ of all buildings (Schmidt 2006).

In the 17th century Apipucos was part of a large farm that dissipated in the middle of the 18th century and in the 19th century it was a region specially used for recreation by aristocratic families of Recife which enjoyed the open spaces and the abundance of water from the Capibaribe River and the Apipucos Lake (Nehren 2006).

Now the typical urban development takes place with paved streets, some public recreation areas and even a university (Universidade Marista). Even if Apipucos is not an agricultural area but composed by urban housings with their gardens and back yards, this open spaces at the southern part of the lake are often used to grow fruits like Mangos, Bananas, Jack-fruits and others just to supply in parts the subsistence of the relatively poor families.

In the northern part of the lake the settlements are a bit better off financially. Here the incomes are better and the housing quality higher, reason why subsistence does not have the same importance as at the southern side. The open spaces are used as recreation areas, planted with plenty of ornamental plants and designed gardens.

Also the educational levels differ considerably between the north and south of Apipucos.

Table 15: Social profile of area-III (Apipucos)

Apipucos			
Nr. of households interviewed:		24	
Educational level of the adults:			
	illiterate:	13	% of the adults
	8th grade (primary level) incomplete:	25	% of the adults
	11th grade (secondary level) incomplete:	42	% of the adults
	11th grade complete:	4	% of the adults
	High-school level complete:	17	% of the adults
Nr. of people/household:		4	
Nr. of Children/household (under 16 y):		1.3	
Household income:		1091.88	BRL/month
Individual income:		247.22	BRL/month
Land tenure:			
	formal:	83	% of the households
	informal:	4	% of the households
	undefined:	13	% of the households
Years passed since migration			
	<10 y:	13	% of the households
	10 to 20 y:	13	% of the households
	>20 y:	75	% of the households
Origin of the settlers			
	urban:	8	% of the settlers
	rural:	13	% of the settlers
	undefined:	79	% of the settlers
Perception of life-quality changes by the leaders			
	it got better:	58	% of the leaders
	it got worse:	17	% of the leaders
	kept unchanged:	25	% of the leaders
Perception of criminality by the leaders			
	low:	38	% of the leaders
	medium:	29	% of the leaders
	high:	33	% of the leaders
	very high:	0	% of the leaders
Health problems (at least 1 person) in households			
	no:	46	% of the households
	yes:	54	% of the households
	Predominant health problem:	Hypertension (HTN)	

6.3.2 Land use structure and its implications

The 24 households interviewed occupy an area of only 1.93 ha what means a medium plot size of 805.40 m². From this area, 55% is sealed ground constructed with houses for generally 4 family members. Since many of the constructions are protected and the area reached a close to complete infrastructure it is not expected that further adensation takes place.

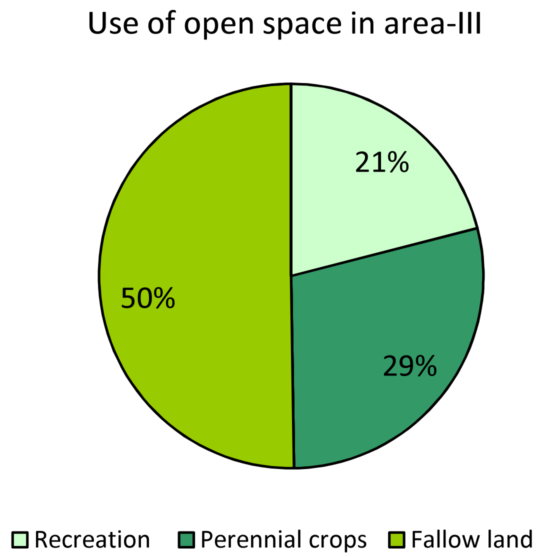


Figure 50: Importance of different land uses in area-III.

Also the land tenure is almost completely defined what means that further illegal invasions or uncontrolled land partitioning will not happen even because there is no space to construct new houses. A new house at the same plot would eliminate completely the open space and seal the ground.

Very interesting is that 50 % of the open space is not used with a definite function and kept fallow. The explanation is that the settlers live an urban live-style, they work in the city and recreation is mostly in the shopping areas and streets or at the beaches of Recife. These locations are all easily accessed with public transport systems or by car and bicycle from Apipucos. So, the backyards seem to lose a little of the attention. Also nice public recreation areas with plenty of space are present in Apipucos and are much more comfortable to meet neighbors or for the kids to play than the small back yards.

Agriculture does not have a place in their daily life. Yet, they use 29 % of the available area to produce all kinds of fruits like coco nuts, bananas, cashew, Lychee, Ananas and others for self consumption.

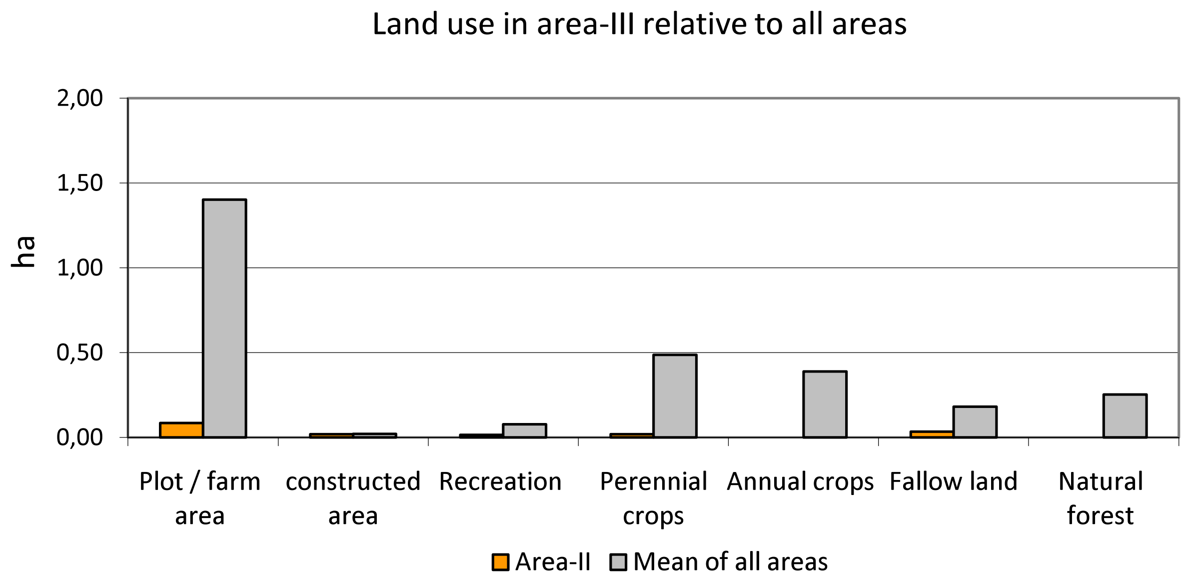


Figure 51: Comparison of land uses in typical household/farm of "Apipucos" (area-III).

6.3.3 Use of space, carbon stocks and resilience index

The low V_{eco} in area-III (22.45 % from the V_{pot}) has two reasons. First the high adensation of housings where almost 55 % of the area is build up and no longer available as an open space for vegetation to develop. Secondly the huge part of the open space covered by fallow land that has a low V_{eco} (17.02 % of the V_{pot}).

Yet, the same fallow land is responsible for pushing the C_i closer to the mean of all interviewed households (0.57 % from the V_{eco} in fallow land systems) together with the 21 % of the area covered with recreation areas that have a C_i of 0.35 % of the V_{eco}. The C_i of area-III is 18.61 % from its V_{eco}.

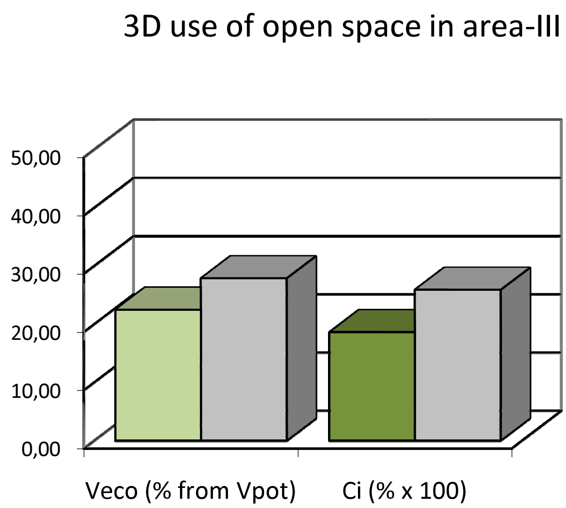


Figure 52: Three dimensional use of open space in area-III compared to the mean of all areas.

The high adensation of housings also reflects in the total carbon stored that is almost the half of the areas-I and II (14.02 against 31.54 and 32.53 t/ha). Per household this means only 1.22 t and per person only 0.31 t of carbon.

Even though, the resilience index of area-III is higher than the mean (0.172). The vegetated area lost by the high adensation of housings is compensated by the high resilience of the recreation areas with a resilience index of 0.206.

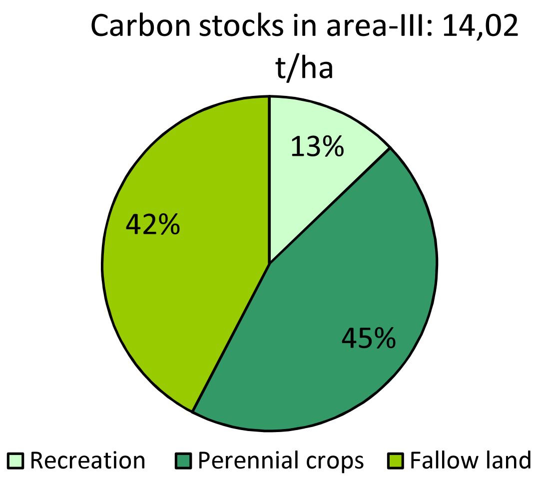


Figure 53: Importance of different carbon pools in area-III.

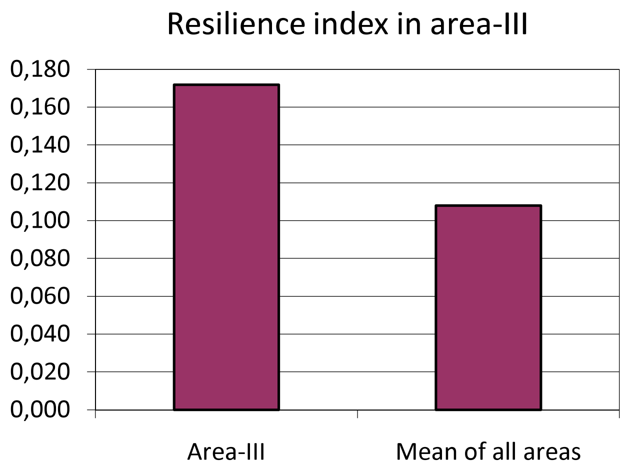


Figure 54: Resilience index of area-III compared to the mean of all areas.

6.4 Area IV: Aldeia

6.4.1 General description

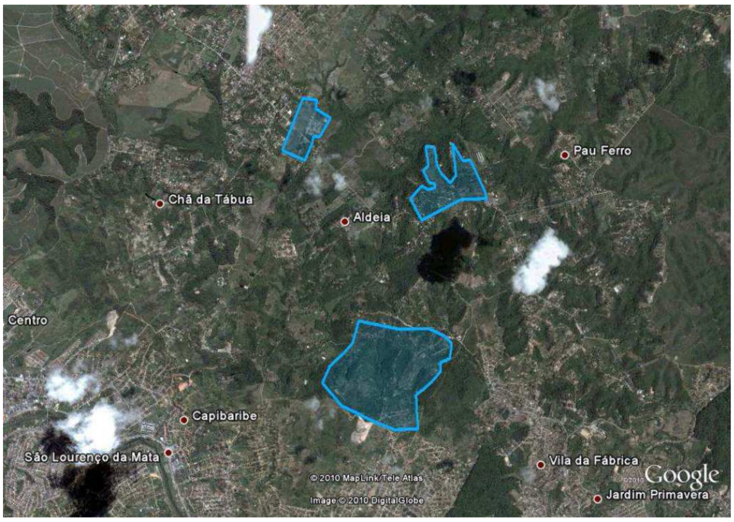


Figure 55: Aldeia.

Aldeia is the name of a peri-urban area around the Estrada de Aldeia in the northwest of Camaragibe, more than 20 km from the center of Recife. Aldeia is not an administrative unit on its own, but split up between the municipalities of Recife, Camaragibe and São Lourenço da Mata.

The area of Aldeia is crossed by a high-voltage transmission line of the CHESF (Hydro electrical Company of the São Francisco). Beyond this triple-rowed power line gardens and fields stretch out for many kilometers. Inhabitants of the surrounding areas cultivate here mainly manioc, okra, sweet potatoes and some banana; during the season also corn, beans and some yam; and maracuja along the fences. As they don't have water for irrigation, the options of production are limited.

The CHESF tolerates this use, as it spares the company spending for regular clearings, as long as certain conditions are kept (no trees, no sugar cane, no houses), which are strictly enforced.

Aldeia has always been popular with the well-off parts of Recife's society, as its climate is very agreeable during the hot summer months. During the last years, the built-up areas of Aldeia have grown considerably. In many parts summer residences and gated communities have replaced agricultural land. Today, agriculture is mostly found in those parts far from the main road, or on areas that can't be used otherwise, such as the area beyond the power lines.

Table 16: Social profile of area-IV (Aldeia)

Aldeia			
Nr. of households interviewed:		12	
Educational level of the adults:			
	illiterate:	50	% of the adults
	8th grade (primary level) incomplete:	25	% of the adults
	11th grade (secondary level) incomplete:	0	% of the adults
	11th grade complete:	8	% of the adults
	High-school level complete:	17	% of the adults
Nr. of people/household:		3	
Nr. of Children/household (under 16 y):		0.9	
Household income:		1212.50	BRL/month
Individual income:		373.08	BRL/month
Land tenure:			
	formal:	42	% of the households
	informal:	17	% of the households
	undefined:	42	% of the households
Years passed since migration			
	<10 y:	33	% of the households
	10 to 20 y:	33	% of the households
	>20 y:	33	% of the households
Origin of the settlers			
	urban:	33	% of the settlers
	rural:	42	% of the settlers
	undefined:	25	% of the settlers
Perception of life-quality changes by the leaders			
	it got better:	42	% of the leaders
	it got worse:	42	% of the leaders
	kept unchanged:	17	% of the leaders
Perception of criminality by the leaders			
	low:	17	% of the leaders
	medium:	58	% of the leaders
	high:	17	% of the leaders
	very high:	8	% of the leaders
Health problems (at least 1 person) in households			
	no:	83	% of the households
	yes:	17	% of the households
	Predominant health problem:	Hypertension (HTN)	

6.4.2 Land use structure and its implications

Aldeia is the farthest of the study areas from the urban influence, even though it is still at the intersection between the urban and the rural landscape. The households analyzed were very heterogeneous, being some of urban settlers that have weekend houses in the hills, maintaining ornamental gardens and diverse fruit trees for their own consumption and others of small farmers that really try to produce more intensively annual crops to sell them in the market and for the own subsistence as mentioned in 4.5.4.1.

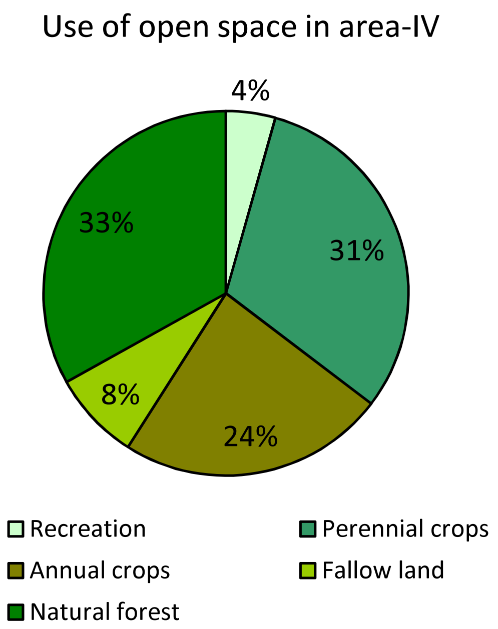


Figure 56: Importance of different land uses in area-IV.

The outcome represents the whole area with its land use diversity and shows that a considerable portion of the land is maintained in its natural form with forest cover (33%). This also explains, what was confirmed in the interviews, why some better-off people from Recife like to keep their weekend houses there.

Agriculture is very important though, 55 % of the open space is used to produce perennial and annual crops. The poor populations tend to produce more annual crops like vegetables and Cassava because they are well accepted in the markets and fast rotating. The better-off classes have large fruit plantations which also serve as recreation areas for the children. Yet they are considered here as perennial crops because the goal is to evaluate them ecologically and typical recreation areas are predominantly composed by ornamental plants in this study.

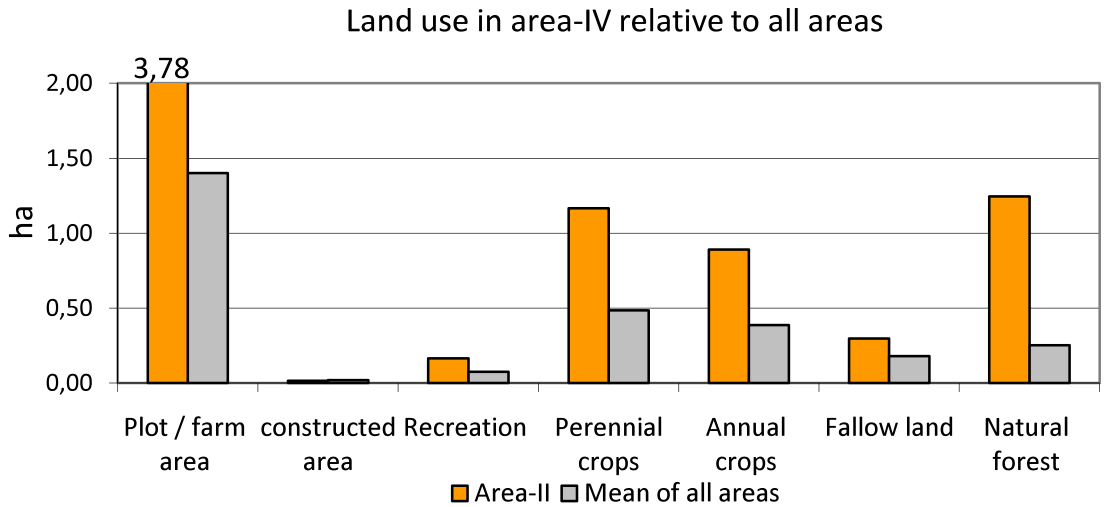


Figure 57: Comparison of land uses in typical household/farm of "Aldeia" (area-IV).

The individual plots are by far the largest (3.78 ha / household). From the 12 households interviewed, two (17 %)are pushing this mean value up, one farm with 20 ha and another farm with 10 ha.

The sizes of the houses build are the same as the mean from all areas (200 m²), yet, these houses are occupied by only 3 people in average.

Also interesting is that there is only 4 % of fallow land what indicates that the open spaces already have a rational use and are managed anyhow by man what reduces the risk of illegal invasions or spontaneous unplanned developments. At least there is a puffer for authorities to control and plan further developments in the landscape scale.

Last but not least, the forest areas, which undergo a passive use, could represent a potential for clearings, invasions or abrupt changes if they are not protected but the community of Aldeia has already organized the "Associacao dos moradores de Aldeia" (Association of the people that live in Aldeia). They hold monthly meetings and a discussion board to react to illegal activities harming their natural kept landscape, to communicate with different stakeholders from the surrounding cities and different community leaders to propose solutions in consensus for such development failures.

6.4.3 Use of space, carbon stocks and resilience index

The diverse and heterogeneous land uses found in area-IV do have a total V_{eco} almost the same as the mean of all interviewed households (27.86 % of the V_{pot}) and a C_i of 0.29 % of the V_{eco}, a little bit (10 %) higher than the mean.

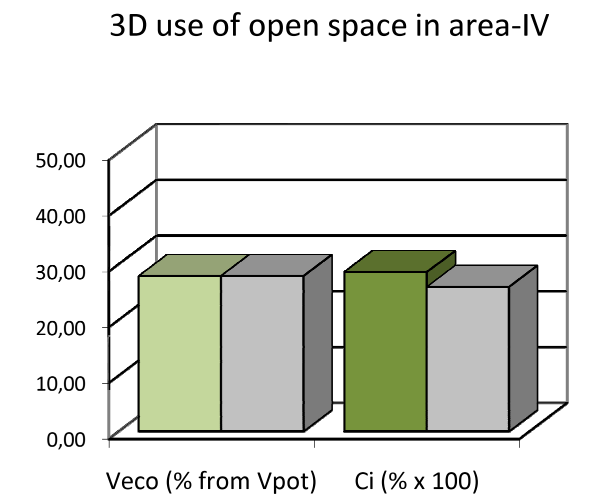


Figure 58: Three dimensional use of open space in area-IV compared to the mean of all areas.

Area-IV stores 19.05 t of carbon per ha, not so much, due to the 24 % of the land covered by annual crops. The large plots or households store 72.09 t each and when this amount is divided by the inhabitants, each person represents 24.03 t of carbon stored in the vegetation in its own household.

The resilience is low, only 0.067 (almost 40 % lower than the mean resilience). This would rank the area-IV somewhere between the pure fallow land system and the perennial crops system of this research.

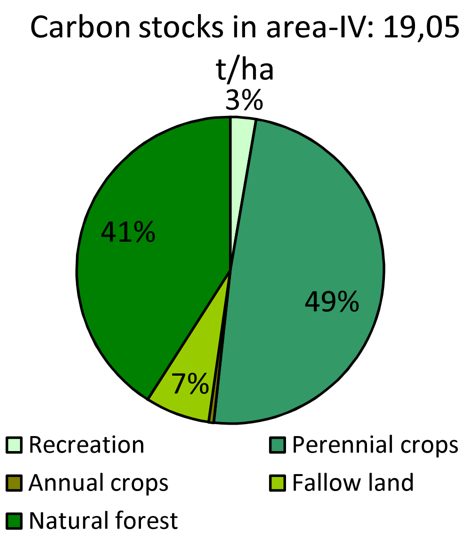


Figure 59: Importance of different carbon pools in area-IV.

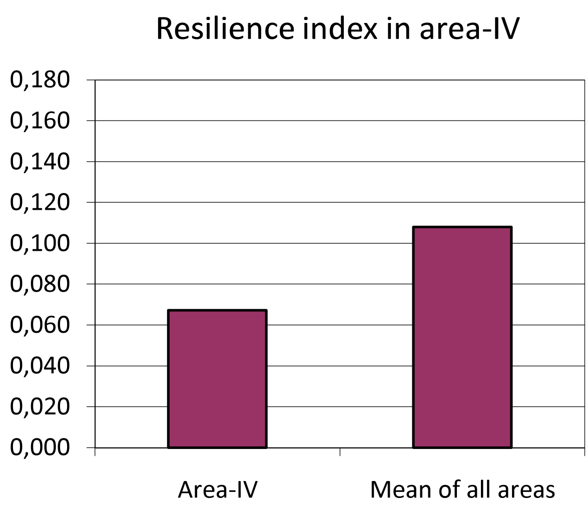


Figure 60: Resilience index of area-IV compared to the mean of all areas.

6.5 Area V: Ceasa

6.5.1 General description

Figure 61: CEASA.

The CEASA (Centre for Nutritional Supply of Pernambuco), the wholesale centre for nutritional and agricultural products in Pernambuco, is situated in the western part of Recife. It is very well connected to road transport, being situated directly at the interchanges of the BR 232 (leading from the city centre to the west) with the BR 101 (passing Recife in south-north direction) and the BR 101 with the Avenida Recife (leading to the airport). The waste land between the interchanges and around the motorways is being almost completely cultivated by small farmers. The cultivation of the area is tolerated as there is no formal occupation or use intended until present, and informal occupation is strictly being prosecuted by the police.

The farmers grow mainly annual crops (mostly vegetables) and sell them directly at the CEASA to the end consumers or on other markets in Recife, taking advantage of the good road access. Interesting is their choice to produce okra, despite the relatively good price for it, okra is difficult to be stolen in huge amounts in a short time. Theft is a serious problem for the farmers, as products that can be easily stolen in sufficient amounts (such as manioc or corn) often disappear shortly before the harvest. Therefore manioc, corn, beans, banana and other fruits and vegetables are mostly grown only in small amounts for personal consumption. The farmers are mostly male, women hardly will be found working there on their own, as violent assaults have happened from time to time.

Most farmers have come from the rural hinterland to the city, have passed a time working as occasional workers in town, but have finally (re)turned to agriculture, when they found an adequate piece of land. They found that agriculture earned them a small but rather regular income and contributed to the household's nutritional supply, while previous urban work had been less hard and often more profitable, but it had been only occasional work interspersed with periods of unemployment, where the household had frequently been left with hardly any income. Agriculture thus did not increase their household's income dramatically, but it contributed to a greater reliability of the income.

Table 17: Social profile of area-V (CEASA)

CEASA			
Nr. of households interviewed:		20	
Educational level of the adults:			
	illiterate:	50	% of the adults
	8th grade (primary level) incomplete:	33	% of the adults
	11th grade (secondary level) incomplete:	17	% of the adults
	11th grade complete:	0	% of the adults
	High-school level complete:	0	% of the adults
Nr. of people/household:		3	
Nr. of Children/household (under 16 y):		0.3	
Household income:		576.67	BRL/month
Individual income:		173.00	BRL/month
Land tenure:			
	formal:	0	% of the households
	informal:	100	% of the households
	undefined:	0	% of the households
Years passed since migration			
	<10 y:	33	% of the households
	10 to 20 y:	50	% of the households
	>20 y:	17	% of the households
Origin of the settlers			
	urban:	33	% of the settlers
	rural:	67	% of the settlers
	undefined:	0	% of the settlers
Perception of life-quality changes by the leaders			
	it got better:	50	% of the leaders
	it got worse:	0	% of the leaders
	kept unchanged:	50	% of the leaders
Perception of criminality by the leaders			
	low:	17	% of the leaders
	medium:	50	% of the leaders
	high:	33	% of the leaders
	very high:	0	% of the leaders
Health problems (at least 1 person) in households			
	no:	67	% of the households
	yes:	33	% of the households
	Predominant health problem:	Hypertension (HTN), heart problems	

6.5.2 Land use structure and its implications

Close to the CEASA market place this settlers specialized themselves into annual crop producers. The 10 ha of land are managed by 6 farmers that represent 6 households with 20 people.

The forces influencing their decisions of weather what to plant and under which technical intensification are far beyond the financial and agronomical implications.

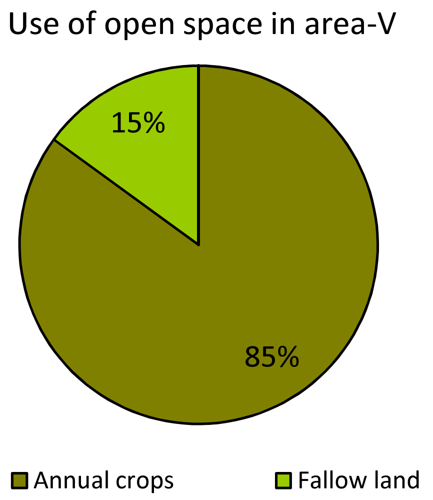


Figure 62: Importance of different land uses in area-V.

Like a real urban agriculture the environment is defined not only by soil, atmosphere and marketing aspects (those are not limiting factors in this area) but also by typical urban problems like car traffic, pollution and last but not least a high criminality. Almost the complete area is cultivated with annual crops (85 %), only a small part is left fallow.

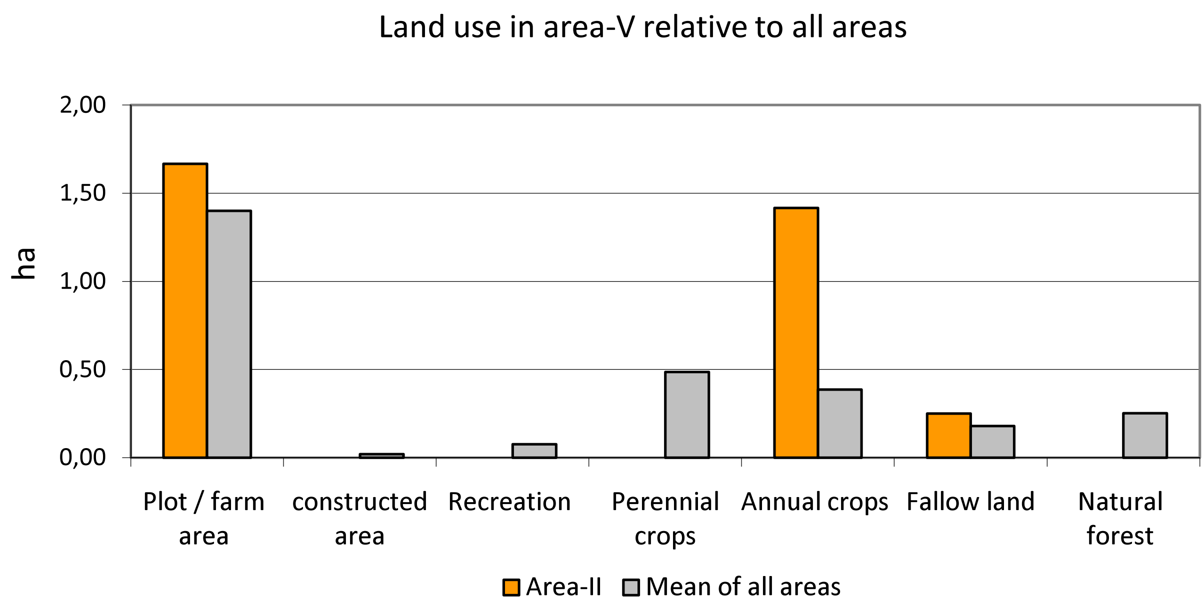


Figure 63: Comparison of land uses in typical household/farm of "Aldeia" (area-IV).

The average area of each plot is 1.67 ha and there are no housings build. It is not permitted to build other houses but the farmers live quiet close to their plantations in poor completely urbanized settlements, as they told in the interviews.

6.5.3 Use of space, carbon stocks and resilience index

This area dominated by annual crops in a completely urban environment makes use of only 10.70 % of the V_{pot} that could be if the whole area was covered by the natural forest system. This is almost 1/3 of the mean V_{eco} across all interviewed households. Thus, the crowding intensity (C_i) is the same as the mean due to the fallow land that covers only 15 % of the area but is very densely crowded (V_{bio} is 0.57 % of the V_{eco}) compared to the annual crops system (where V_{bio} is only 0.19 % of the V_{eco}).

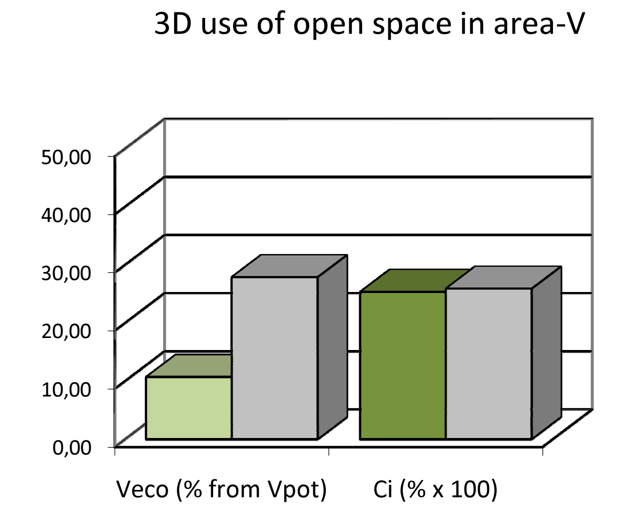


Figure 66: Three dimensional use of open space in area-V compared to the mean of all areas.

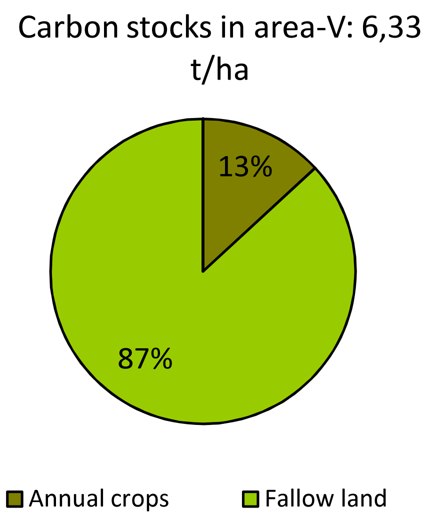


Figure 64: Importance of different carbon pools in area-V.

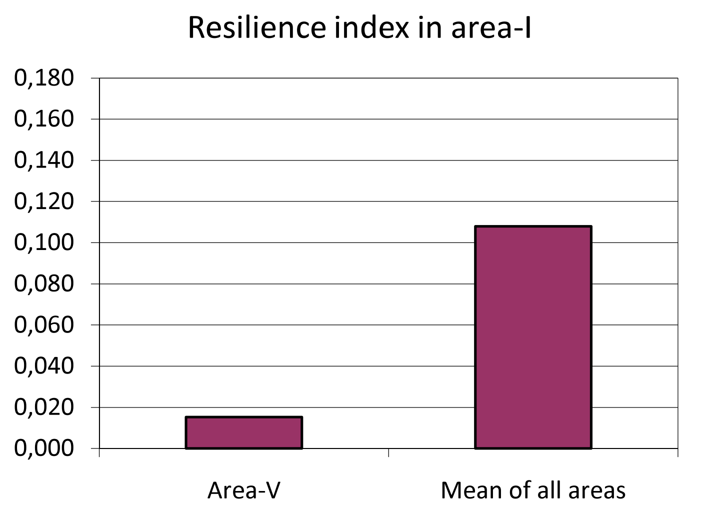


Figure 65: Resilience index of area-V compared to the mean of all areas.

The total amount of carbon stored is very low, only 6.33 t/ha. Interesting is that in the same moment when the largest area is covered by annual crops, the most important contributor to the carbon stocks is the fallow land system (87 % of the carbon stored in fallow land)

This very simplified land use system also gives the area-V a low resilience index of 0.015, only 15 % from the mean of all interviewed households. The low resilience of the annual crops system (0.009) is a little bit compensated by the area covered with fallow land.

6.6 Area VI: Ilha dos bananais

6.6.1 General description

Maybe the most exotic area of all, the Ilha dos Bananais is a fluvial Island located in the north-western part of Recife, south of the Apipucos area, surrounded by an urban landscape. The whole Island has an area of 6 Ha. and there are about 5 small farms on it.

Figure 67: Ilha dos bananais.

It was not possible to see all of them and evaluate, because a part of the island is dominated by criminal groups. Yet, two farms could be studied and the outcome is pretty interesting. There are no housings or roads in the whole island, because it is really isolated by water and the land tenure situation is totally informal.

The farmers found an alternative to survive inside the city, producing fruits and vegetables in ecologically sound systems. Not because of this consciousness in first place, but due to the fact that no financial resources are available and transportation across the river is very effort demanding. In small boats they are able to transport only little quantities of products to the local market. The systems are structured in different layers composed of different value crops together, mostly perennial crops like bananas and coco nuts.

About 20 years ago, the area was a brick company that went bankrupt and left big degraded craters behind. The cultivation of these areas has restored the soil characteristics and now represents an important ecological niche in this always growing city.

Violence around the island is still the most important barrier for researchers and politicians to visit and understand this place in a manner to improve the positive aspects of such very particular reality.

Table 18: Social profile of area-VI (Ilha dos Bananais)

Ilha dos bananais			
Nr. of households interviewed:		2	
Educational level of the adults:			
	illiterate:	50	% of the adults
	8th grade (primary level) incomplete:	50	% of the adults
	11th grade (secondary level) incomplete:	0	% of the adults
	11th grade complete:	0	% of the adults
	High-school level complete:	0	% of the adults
Nr. of people/household:		4	
Nr. of Children/household (under 16 y):		2.0	
Household income:		275.00	BRL/month
Individual income:		68.75	BRL/month
Land tenure:			
	formal:	0	% of the households
	informal:	100	% of the households
	undefined:	0	% of the households
Years passed since migration			
	<10 y:	0	% of the households
	10 to 20 y:	100	% of the households
	>20 y:	0	% of the households
Origin of the settlers			
	urban:	100	% of the settlers
	rural:	0	% of the settlers
	undefined:	0	% of the settlers
Perception of life-quality changes by the leaders			
	it got better:	100	% of the leaders
	it got worse:	0	% of the leaders
	kept unchanged:	0	% of the leaders
Perception of criminality by the leaders			
	low:	0	% of the leaders
	medium:	50	% of the leaders
	high:	0	% of the leaders
	very high:	50	% of the leaders
Health problems (at least 1 person) in households			
	no:	100	% of the households
	yes:	0	% of the households
	Predominant health problem:	-	

6.6.2 Land use structure and its implications

The two farms that were analyzed have in total 10.30 ha divided in almost equal parts. This represents 30 % of the whole Island area.

78 % of the area (excluding the constructed area) is managed with perennial crops that are sold in the city. Only 1 % (72 m²) is planted with some vegetables and cassava for self consumption.

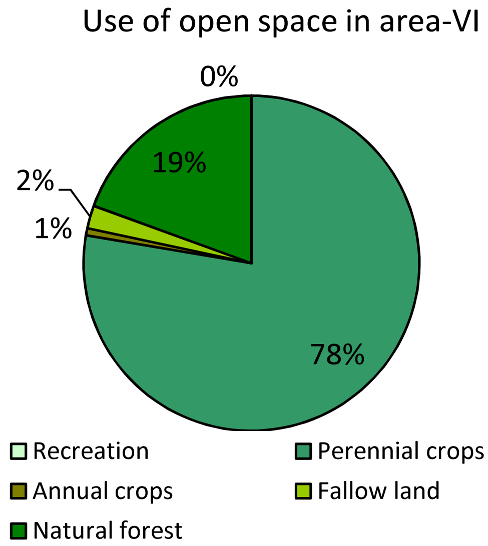


Figure 68: Importance of different land uses in area-VI.

The specialization in perennial crops is a response of the farmers to the extreme degraded conditions they faced when the former brick company went bankrupt. With the planting of fruit trees they could restore the soil and create a fertile organic layer on the top soil and prevent the strong erosion processes that harmed the island before.

Another 19 % are kept in natural forest conditions because the fragments were already there and prevented the Island of eroding completely in the past. The forest

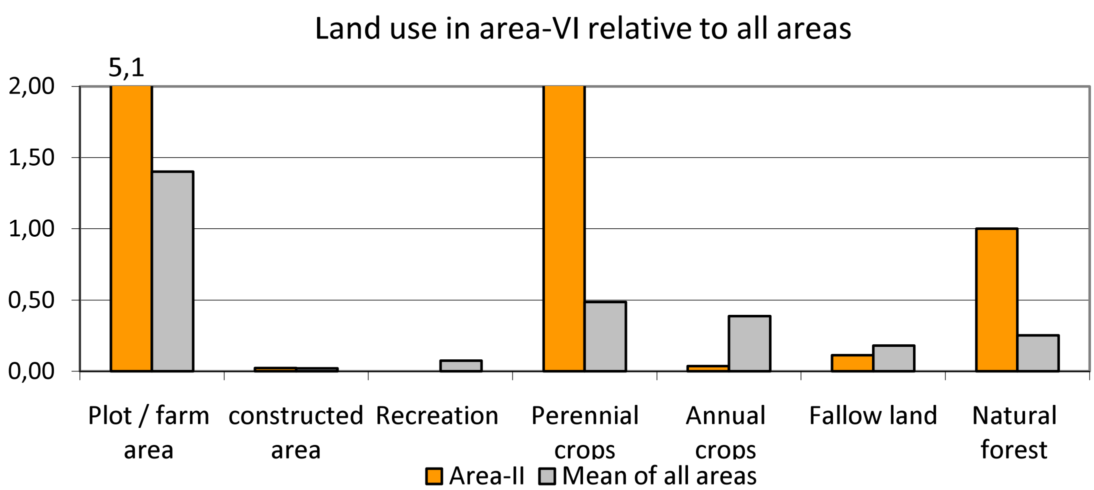


Figure 69: Comparison of land uses in typical household/farm of the "Ilha dos Bananais" (area-VI).

fragments also create a natural separation to the western part of the Island where drug dealers prevail. In Figure 67 it is possible to see that this part of the Island is quiet less vegetated than the part managed by the farmers.

The farms (plots) are up to 4 times larger than the mean of all areas, even if located inside a predominantly urban landscape with tall buildings around. The isolation provided by the Capibaribe River is responsible for that.

Yet, the high degree of criminality (personal experience) isolates the Island from all kind of public services like security, health systems and universities that could create management plans together with public institutions to integrate the Island to the city around it.

Being the only people interested in cultivating that land (also by the leak of alternatives), they could construct houses of 200 m² that are occupied by 4 family members.

6.6.3 Use of space, carbon stocks and resilience index

Area-VI makes the best use of space from all areas. V_{eco} occupies 50.63 % of the V_{pot} and with a C_i (0.28 % from the V_{eco}) even a little higher than the mean of all interviewed households (0.26 % from the V_{eco}).

Carbon stored (58.22 t/ha) is almost twice as much as the carbon stored in the next best area, the "Assentamento Macacos e Pedreiros" (area-II) (32.53 t/ha). With the largest plots stocking 299.83 t per household, the stock per inhabitant is the highest with 74.96 t of carbon.

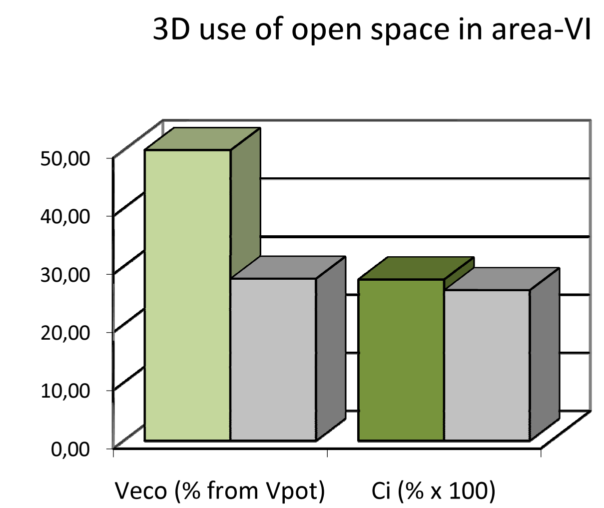


Figure 70: Three dimensional use of open space in area-VI compared to the mean of all areas.

Area-VI has a high resilience index of 0.108 which is predominantly produced by the perennial crops but tuned a bit by the area covered by the of natural forest system.

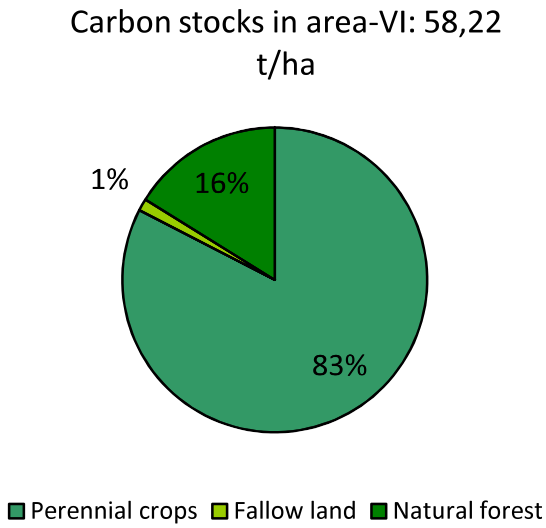


Figure 71: Importance of different carbon pools in area-VI.

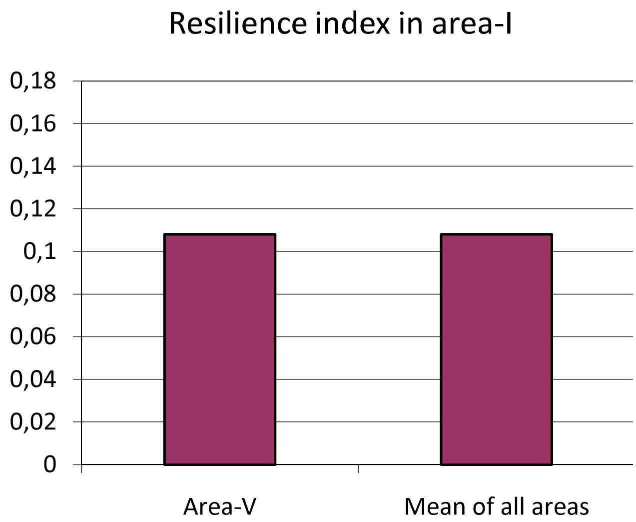


Figure 72: Resilience index of area-VI compared to the mean of all areas.

7 GENERAL DISCUSSION

In this chapter the results from the field measurements, interviews and calculations will be presented first with a focus on the single land use systems (the experimental systems) and their ecological implications, second from a broader point of view with the land use systems in a context of a landscape that undergoes changes defined by decisions on a household level. A recommendation for further studies and methodologies will be discussed as well as a possible strategic scenario of land use change that can maintain carbon stocks in open spaces neutral up to a certain point in the urbanization process while maintaining the intrinsic functions of open spaces for their users.

7.1 Ecological implications of the land-use systems

A broad range of land use systems were analyzed and classified in the first instance into six specific categories: Natural forest, perennial crops, recreation areas, fallow land, street trees and annual crops. This range accommodates the different functions that open spaces have to fulfill in urban (-izing) areas. Their structure and composition is a result of individual management practices applied by their holders which aim to supply very specific demands under adverse legal, financial, socio-cultural and environmental conditions. The ecological implications of the resulting land use systems are a by-product of other priority functions that are pursued like income, recreation, comfort added value of land and in some cases strategic land occupation, in accordance to Töpfer (2007) and Wiebel (2008). In this chapter the ecological implications of each type of resulting land use system will be discussed without considering the complex processes that are responsible for their existence, distribution and change.

As well as their priority functions, the analyzed land use systems show very heterogeneous ecological implications (Table 19).

Table 19: Summary table: Ecological implications of the land-use systems

	Natural forest	Perennial crops	Recreation areas	Fallow land	Street trees	Annual crops
V_{eco} (m³)	148253.00	63152.20	86818.70	25226.60	20291.60	13987.00
V_{eco} (% of V_{pot})	100.00	42.60	58.56	17.02	13.69	9.43
C_i (%)	0.17	0.29	0.35	0.57	0.38	0.19
R_i	0.156	0.102	0.206	0.047	0.044	0.009
Diversity (n° of species)	43	24	62	33	7	20
Carbon stocked (t/ha)	48.33	61.77	24.23	33.48	15.24	0.90
Carbon fixed (t/ha/y)	1.29	1.65	0.65	0.89	0.41	10.34
Carbon exported (t/ha/y)	0.00	1.40	0.42	0.42	0.41	9.44
Energy stored (J/ha)	2.20E+06	2.82E+06	1.10E+06	1.53E+06	6.95E+05	9.67E+05
Energy produced (J/ha)	5.88E+04	7.50E+04	2.94E+04	4.07E+04	1.85E+04	1.12E+07
Energy exported (J/ha/y)	0.00E+00	6.36E+04	1.92E+04	1.92E+04	1.85E+04	1.02E+07
Albedo (%)	10-15	10-15	10-15	12-30	10-15	12-30
CP_i	1.67	0.65	0.58	0.11	0.02	0.13

When using the three dimensional approach (chapter 5.3) to understand their structure the results show that the volume (V_{eco}) available for the system to develop its natural dynamics such as diversification (biodiversity) and succession processes (biomass production and allocation) is by far highest in the natural forest systems (148253.00 m³) followed by the recreation area systems and the perennial crop systems which have 58.56 and 42.60 % of the potential V_{eco} (V_{pot}) respectively.

The fallow land, street trees and annual crop systems have a volume less than 18% from the volume available for the natural forest system. In the street trees and annual crop systems this reduced V_{eco} also is accompanied by the lowest resilience index (R_i) (0.044 and 0.009 respectively) and the lowest species richness (7 and 20 species found respectively), corresponding closely to the results from Torrico (2006). Yet in the fallow land system, which is almost a natural forest system kept artificially in a very initial development stage, the natural processes of diversification and succession can develop up to the next time the land is cleared. As a result the fallow land systems make a better use of the available volume crowding it more intensively than any other system (C_i = 0.57 %), resulting in a higher R_i (0.047) than the street tree and the annual crop systems.

The species richness in the fallow land systems is even higher than in the perennial crop systems (33 and 24 plant species respectively). Carbon stocks in fallow land systems are almost the double of the ones in the street tree systems (33.48 and 15.24 t/ha respectively) and the 37.2 fold of the annual crop systems which store the lowest amounts of carbon (0.90 t/ha), even at a similar V_{eco}. Similar values were found by Baumert (2008) in Ketou – Benin. Responsible for the high C_i and carbon stocks are mainly some sparse left over trees in strata-4 that are not cut when clearings occur (Figure 30).

The highest R_i, and thus the ability to restore natural conditions, are found in the recreation area systems (0.206) and is accompanied by the highest plant diversity (62 plant species found) even if compared with the natural forest system that has 43 plant species. The difference is that in the natural forest system 57% of the species are native while in the recreation area system only 30% are. This system stores only 24.23 t/ha of carbon (Figure 30), even less than the fallow land system (33.48 t/ha) that has an almost 70% lower V_{eco} (Figure 31) but as mentioned above, a higher C_i. Natural forest systems showed relatively low plant diversity because they are fragments in fact not developed to their climax stage where they could be composed of up to 263 plant species according to Torrico (2006).

The highest carbon stocks are found in the perennial crop systems (61.77 t/ha) and are followed by the natural forest systems (48.33 t/ha). Even with a 43% lower V_{eco}, the C_i in the perennial crop systems is 67% higher than in the natural forest system. The higher carbon stocks are resulting from larger basal areas of individual trees in strata-2 (0.09 against 0.02 m^2/pl respectively) and strata-3 (0.22 against 0.03 m^2/pl respectively) (Figure 25). The lowest carbon stocks were found in the street tree and in the annual crop systems (15.24 and 0.90 t/ha respectively). As a comparison, Stoffberg (2010) measured 3.40 t/ha for street trees in Tshwane – South Africa. Already mentioned, they have the lowest V_{eco}, the lowest plant diversity and the lowest Ri. In both systems the yearly fixed carbon is almost completely exported from the system. From the street tree system 0.41 t/ha of carbon are exported by pruning (100% of the litter fall). The annual crop systems have the highest carbon fixation rates (10.34 t/ha/y) but almost 90% is exported at the harvest (Table 12).

The cooling potential of the experimental systems has a rather local than global relevance. The CP_i is strongly determined by the system structure and its productivity (EVT), being one the delimiting factor of the other. Especially in the annual crop system that has by far the highest EVT (bound on yearly carbon fixation), almost six times higher than the most productive systems, the system structure delimits the cooling potential from EVT (ECP_i).

While the natural forest system has the highest CP_i, annual crops and recreation areas are similar, yet the recreation area systems have the highest SP_i determined by their structure what is according to their function to provide a spacious and cooled microclimate for the settlers, rather than to be productive in terms of biomass production. In the natural forest system both, ECP_i and SP_i are at highest levels.

7.2 General implications of land-use change (LUC)

With the world's urban population expected to reach 5.5 billion in 2025 (Greenidge 1999), the urbanization process is one of the most important causes of land use change (Cure 2007).

Analyzing the socio-economical, cultural and ecological implications of the overall study area it is possible to define it as peri-urban (Marshall et al. 2009) due to its location (Figure 23) at the edge of Recife, due to the presence of rural activities (Figure 38, Figure 44, Figure 50, Figure 56, Figure 62, Figure 71) and the movement of goods and services between the urban and the rural areas described in the cases of Chapter 6. The following Table 20 shows in summary the most important aspects of the study areas.

Table 20: Summary table: Ecological implications of LUC

	Area-I	Area-II	Area-III	Area-IV	Area-V	Area-VI	Mean*
Plot size (ha)	0.71	1.95	0.08	3.78	1.67	5.15	1.40
Ground sealing by buildings (%)	3.34	1.29	22.65	0.44	0.00	0.45	4.70
People in the Household (no°)	4	6	4	3	3	4	4
Income per household (BRL)	973.98	733.64	1091.88	1212.50	576.67	275	810.61
Informal land tenure situation (%)**	73	100	17	59	100	100	74.83
Very low educational level (%)***	73	50	38	75	83	100	69.83
V_{eco} (% of V_{pot})	36.88	26.75	22.49	27.86	10.7	50.63	28.18
C_i (%)	0.28	0.31	0.19	0.29	0.25	0.28	0.26
Carbon stored (t/ha)	31.54	32.53	14.02	19.05	6.33	58.22	24.78
Resilience index	0.129	0.063	0.172	0.067	0.015	0.108	0.108
Energy stocks (J/ha)	1.58E+08	2.39E+08	7.21E+06	6.82E+08	2.45E+06	1.60E+09	2.30E+08
Energy production (J/ha/y)	4.38E+06	2.23E+07	2.80E+05	3.68E+07	2.91E+07	4.37E+07	1.45E+07
Energy exported (J/ha/y)	2.78E+06	1.91E+07	2.01E+05	2.60E+07	2.62E+07	3.22E+07	1.13E+07

* Mean value across all interviewed households
**sum of informal and undefined
***leaders with primary level incomplete

Generally the households analyzed show a high degree of informality regarding the land tenure and a very low educational level of the leaders, corresponding to the data from Wiebel (2008). The plot areas are relatively large from the urban perspective (1.4 ha mean) except in area-III where the individual plots have 800 m².

This area is geographically and conceptually the closest to urban structures (Marshall et al. 2009), shows one of the highest incomes, the lowest degree of informality and the best educational levels of the leaders. The agricultural activity is rather reduced to the consumption of fruits in the households and not providing income.

The carbon stocks (14.02 t/ha) are relatively low in area-III compared to more rural areas even with its open spaces covered by land use systems with high carbon stocks per unit of area (Figure 53). Yet, 50% of the open space is kept fallow, without direct function for the settlers.

The conversion of this fallow land into a more productive system like the perennial crop system could increase considerably (conversion factor 1.85 in Table 21) the total carbon stocks from 14.02 to 19.02 t/ha (increase of 35.66%) but this area would still be storing less carbon than areas I, II and VI and similar amounts as area-IV.

Interesting also is the very high R_i in this area of 0.172 that is especially resulting from the 21% of open space covered by recreation areas and a conversion of the fallow land system to perennial crops would influence the R_i positively.

Table 21: Carbon stocks and LUC conversion factors

A \ B	Natural forest	Perennial crops	Recreation areas	Fallow land	Street trees	Annual crops
Natural forest	1.00	0.78	2.00	1.44	3.17	54.00
Perennial crops	1.28	1.00	2.55	1.85	4.05	69.01
Recreation areas	0.50	0.39	1.00	0.72	1.59	27.07
Fallow land	0.69	0.54	1.38	1.00	2.20	37.40
Street trees	0.32	0.25	0.63	0.46	1.00	17.02
Annual crops	0.02	0.01	0.04	0.03	0.06	1.00

*Grey cells are changes from A to B that make land available for urbanization maintaining carbon stocks neutral

All other areas (I, II, IV, V and VI) have in common the high degree of informal or undefined land tenure situation. While this situation creates a chance for uncontrolled expansion of agricultural land, it also creates a chance for the uncontrolled expansion of buildings and sealed (not open) land (personal interviews and in accordance to Wiebel 2008).

Creating hypothetical land use change scenarios in this context would at least be speculative for the moment. While the integration of these areas into the master plan of Recife and their future development is a complex political issue and thus not elemental part of this research, it is still possible to recommend the compensation of reduced carbon stocks from lost open spaces by the proportional increase of carbon stocks in left open spaces.

For example, each land use system (in unit area) of column “A” (Table 21) can be converted to a land use system (in unit area times the conversion factor) of column “B”, while maintaining the carbon stocks neutral. This would mean that the lost of 300m² of fallow land for building purposes can be compensated by 162 m² of perennial crop systems (300 m² x 0.54) or by 660 m² of street tree systems (300 m² x 2.20) in another area.

Of course this new area would also suffer a change which has to be compensated proportionally. This would not be the case if areas with no vegetation at all would be used for the carbon stock compensation like the reforestation of degraded areas or shade trees on sidewalks.

Nevertheless the compensation of carbon stock reductions through land use change has other ecological implications that have to be weighed by the decision makers. Those implications are illustrated in Table 22.

Table 22: Matrix: Ecological implications of land use change (LUC)

		NF	PC	RC	FL	ST	AC
Natural forest	C-st.		+	−	−	−	−
	CP_i		−	−	−	−	−
	E-st.		+	−	−	−	−
	E-prod.		+	−	−	−	+
	V_{eco}		−	−	−	−	−
	C_i		+	+	+	+	+
	R_i		−	+	−	−	−
	Pl. div.		−	+	−	−	−
Perennial crops	C-st.	−		−	−	−	−
	CP_i	+		−	−	−	−
	E-st.	−		−	−	−	−
	E-prod.	−		−	−	−	+
	V_{eco}	+		+	−	−	−
	C_i	−		+	+	+	−
	R_i	+		+	−	−	−
	Pl. div.	+		+	+	−	−
Recreation areas	C-st.	+	+		+	−	−
	CP_i	+	+		−	−	−
	E-st.	+	+		+	−	−
	E-prod.	+	+		+	−	+
	V_{eco}	+	−		−	−	−
	C_i	−	−		+	+	−
	R_i	−	−		−	−	−
	Pl. div.	−	−		−	−	−
Fallow land	C-st.	+	+	−		−	−
	CP_i	+	+	+		−	+
	E-st.	+	+	−		−	−
	E-prod.	+	+	−		−	+
	V_{eco}	+	+	+		−	−
	C_i	−	−	−		−	−
	R_i	+	+	+		−	−
	Pl. div.	+	−	+		−	−
Street trees	C-st.	+	+	+	+		−
	CP_i	+	+	+	+		+
	E-st.	+	+	+	+		+
	E-prod.	+	+	+	+		+
	V_{eco}	+	+	+	+		−
	C_i	−	−	−	+		−
	R_i	+	+	+	+		−
	Pl. div.	+	+	+	+		+
Annual crops	C-st.	+	+	+	+	+	
	CP_i	+	+	+	−	−	
	E-st.	+	+	+	+	−	
	E-prod.	−	−	−	−	−	
	V_{eco}	+	+	+	+	+	
	C_i	−	+	+	+	+	
	R_i	+	+	+	+	+	
	Pl. div.	+	+	+	+	−	

Positive LUC effects

Negative LUC effects

List of abbreviations:

NF = Natural forest
PC = Perennial crops
RC = Recreation areas
FL = Fallow land
ST = Street trees
AC = Annual crops

C-st. = Carbon stocks in t/ha
CP_i = Cooling potential index
E-st. = Energy stocks in J/ha
E-prod. = Energy stocks in J/ha/y
V_{eco} = Eco volume in m^3
C_i = Crowding intensity in %
R_i = Resilience index
Pl. div. = Plant diversity in n° of sp.

7.3 Future outlook: Emergy analysis and sustainability

The *Global Report on Human Settlements 2009* (UNHABITAT 2009) analyzed the role of urban planning as a tool to achieve the challenge of sustainable urban development and concluded that especially in developing countries the current urban planning approach has "*…failed to accommodate the ways of life of the majority of inhabitants in rapidly growing and largely poor and informal cities, and has often directly contributed to social and spatial marginalization*." The results in Chapter 6 show that the areas analyzed fit into this reality. This report also mentions the goals that have to be pursued globally by urban planners and decision makers for a sustainable urban development which can be summarized as follows:

- Environmental goals
  - Reduction of green house gas emissions
  - Reduction of the urban sprawl (more efficient public transport systems)
  - Efficient use of non-renewable and conservation of renewable resources
  - Efficient use of energy and reduction of waste
  - Recycling of waste
- Economical goals
  - Local economic development; large, small, formal and informal enterprises
  - Reliable infrastructure and services
  - Access to land with secure tenure
  - Capable financial institutions (mobilization of investment and credit)
  - Capacitation of the workforce
  - A legal system which ensures competition, accountability and property rights
  - Appropriate regulatory frameworks
  - Special attention to the informal sector
- Social goals
  - Fair and equitable provision of services with equal quality
  - Social integration
  - Gender and disability sensitive planning
  - Elimination of violence and crime

In this research the ecological implications of the studied open spaces and their importance as carbon stocks were quantified and further analyzed in a regional context and on a household/farm scale (the management unit). The gained information can support planners and decision makers to pursue ecological goals for a sustainable urban planning of Recife. Yet, the results also show the complex socio-economical landscapes in which the management units are integrated. It is necessary to understand better the social and economical implications of the studied land use systems to potential the importance of the gained information for urban planning approach that address the mentioned goals for a sustainable development.

The integration of the ecological, economical and social dimensions into a common research framework is possible with the emergy analysis methodology (emergy spelled with an "m") proposed by Odum (Li 2007). Emergy means "embodied energy" and can measure the work (input) of natural and human systems necessary to produce products and services (output) using a universal unit which is the solar emergy emjoule (sej) (Odum 1996). In other words it is possible to compare the energetic efficiency of distinct systems, for example an ecological farming systems vs. intensive vegetable production systems (Torrico and Janssens 2009) and relate them to the energetic efficiency of a broad system in which they are integrated like a city (Li 2007) or a whole country like Brazil (Safonov et al. 1999).

The input data for the emergy analysis comprises a broad range of quantitative internal and external variables. Those are categorized into renewable natural resources (sun, wind, nutrients, water, etc.), non-renewable natural resources (soil), materials from the economy (fuels, fertilizers, building material etc.) and services from the economy (man power, insurance costs, taxes, infrastructure, communication costs, etc.). Each variable is converted into its equivalent solar emergy content (sej) using a transformity which is the ratio between the emergy used in the process of producing one unit of each variable and its energy content. For example to calculate the ratio of solar mjoules per monetary unit one can divide the total emergy use of a nation by its gross economic product (Brown and Ulgiati 2004). Important for the system analysis is in first instance the delimitation of the system to be evaluated. In the emergy analysis special symbols are used to represent the system boundary, flows, stocks and processes that involve the transformation of emergy input, through the stocks and transformations of inside the system and to the output in form of a product or service. A simplified example can be seen in Annex 3 and the symbols are explained in Annex 4.

The final evaluation of the data can classify different systems hierarchically according to different indicators produced. Those are the transformity (sej/J), net emergy yield ratio (EYR), emergy investment ratio (EIR), environmental loading rate (ELR), renewability (%R) and emergy exchange ratio (EER). The calculations to those indicators can be seen in Annex 3 as well.

Figure 73: Effect of strategic landscape design on the criminality in the city of Vinhedo, Brazil. Source: Winters 2005.

In the context of this particular research it would mean that the energy stored in the biomass and exported from the different land use systems (Table 12) would gain a qualitative character. Yet, while in the agricultural and natural systems the output can clearly be quantified, converted into emergy units (sej) and brought into relation to the emergy used to produce them, in recreation areas and in perennial crop systems that are not commercially used it would be necessary to create a quantitative value for subjective outputs like relaxing, socialization, beauty and so on. One possibility is to quantify the reduced social costs of criminality. Figure 73 illustrates the effect of a strategic investment in professional landscape design realized between 1998 and 2005 in the city of Vinhedo in Sao Paulo, Brazil, on the reduction of registered robberies. The project included the re-design of public recreation areas with the objective to increase life quality of the settlers (official website of Vinhedo 2009).

7.4 Prospective/strategic open space planning approach for the peri-urban fringe of megacities

In this chapter some prospective possibilities for the design and use of open spaces, especially in rapidly growing urban areas will be exposed and discussed starting with the most intrinsic needs that have to be addressed by a sustainable open space planning approach and ending with a prospective vision and scenario that could be applied in open space planning.

As seen in the socio economic profiles of the different study areas (cases) in chapter 6, the typical problems in the peri-urban areas as well evidenced by Cure (2007) and Marschall (200), especially in the developing world, are evident: high degree of informality, unclear land tenure situations of squatters, deficit infrastructure and job opportunities, social segregation and the lack of services.

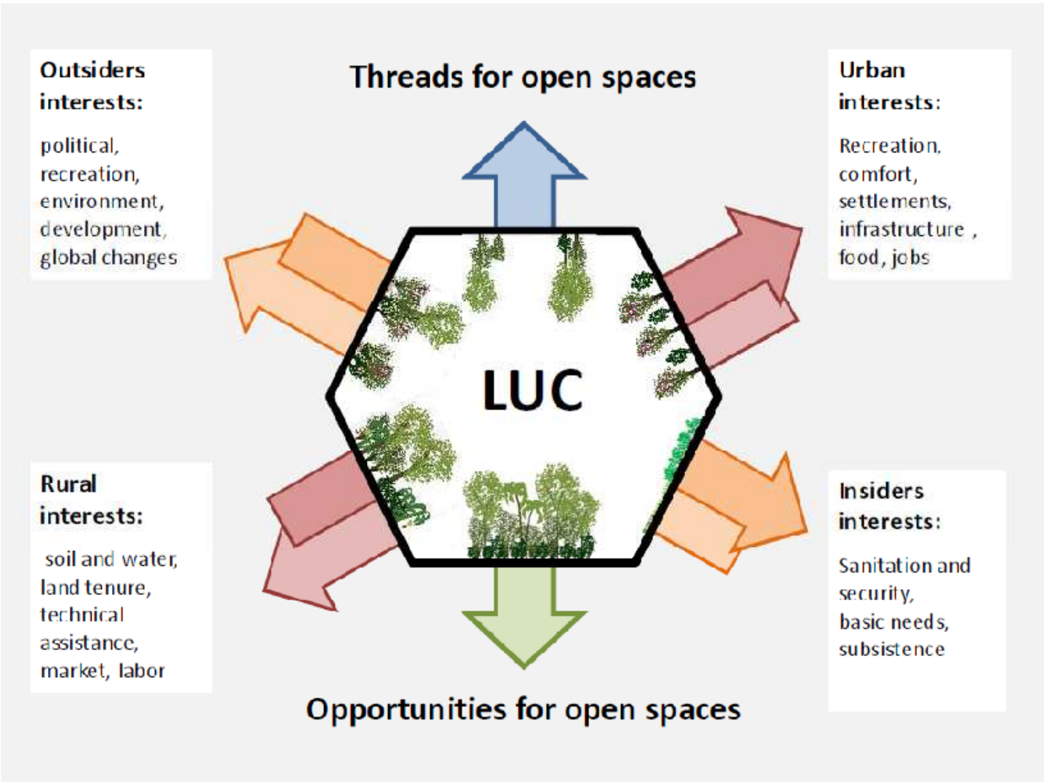


Figure 74: Conflicting interests in the peri urban fringe: Opportunities and threads for LUC and open spaces.

The land use and land use change is subject to be molded by the primary needs of the actors. For example in the analyzed area-I an unproductive fallow land use system is subject of being invaded illegally for building purposes if the increasing population demands for housings while a large fruit tree will be preserved by the community as a reference point for recreation and socialization due to the shade, fruits and beauty it provides. This value of open space is well described by Töpfer (2007). Carbon stocks and other ecological implications are of indirect importance for the actors (insiders) that decide on open spaces in such an informal context unless the basic and direct needs are given. Figure 74 illustrates the conflicting interests to which open spaces in peri-urban areas are exposed and the opportunity window for a sustainable open space planning.

To convert conflicts into synergies it is necessary first to increase the direct importance of open spaces to the actors in the lower levels of the decision making process like private households and farmers, no matter if their influence on open spaces is formal or informal. Secondly it is important to stress out the regional and global implications of LUC in the peri-urban areas in the higher levels of the decision making process (outsiders) such as local authorities and governments. The conflicting interests and the opportunity windows have to be considered along the urbanization process to enable practical solutions in all administrative levels.

Capacity building plays a crucial role in the planning process of open spaces (Allen et al. 1999) and has to match the awareness of the opportunities with a realistic decision process.

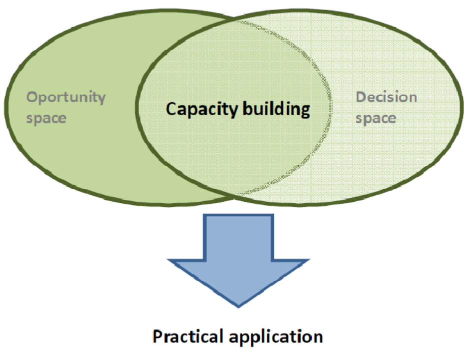


Figure 75: Capacity building as a tool for open space planning.

As an example, the planting of street trees offers many opportunities like the use of native species for biodiversity increment and tall trees to increase shade, carbon stocks and the cooling effect. But the power lines limit their heights to five meters what implicates in extra maintenance costs for pruning or investments to transfer the power lines to underground systems. If the decision space is limited, the opportunity space is reduced as well.

The results of this research are a contribution to the understanding of the opportunity space illustrated in Figure 75. The following discussion will emphasize some elements from the opportunity space and how they can be matched with elements from the decision space to enable a practical application of the results of this research.

In the first instance, open spaces are “open” because they are the alternative to “closed” or sealed areas (Töpfer 2007). The growth of urban areas is bound to the reduction of land available for plants to grow. The three-dimensional system analysis approach explained in chapter 4.5.3 and applied to the open spaces in chapter 4.5.3 shows that the increase of the vertical dimension (eco height = H_{ecos}) can compensate partially the reduction of a horizontal dimension (area) while maintaining carbon stocks equal (Table 21). It was seen in chapter 7.2 that even in a relatively green urban neighborhood (area-III described in chapter 6), when the urban open and not open spaces are considered to be part of one system, the increased H_{ecos} in fact do not compensate carbon stocks found in rural areas.

In order to push the interactions and stabilizing processes between natural and social systems (also evidenced by Huang and Chen 2005), increasing carbon stocks and resilience of open spaces, the first and most intrinsic step is to increase the efficiency of already existing open spaces and land use systems. An interesting practical design approach is suggested by Bill Mollison and called Permaculture (permanent culture). Not entering into ethical or philosophical issues, permaculture follows very simple and applicable principles to design productive systems, inspired by the flows of matter and energy found in natural systems (Whitefield 2005). The goal is to increase as much as possible the interactions between the elements in a system. By a proper design, the same element can fulfill many different functions and create a more complex network of interactions (Mollison 1988).

The objective is that the system does as much work as possible, turning it as independent from external inputs as possible, stable and permanent while supplying social demands as well. Figure 76 illustrates the potential of one single tree if selected and planted at the right place and its role in stabilizing not only the natural but also the social systems such as a household or a city (right side). A lot more detailed practical examples can be found in literature, including not only the design of natural but also of artificial architectonic elements.

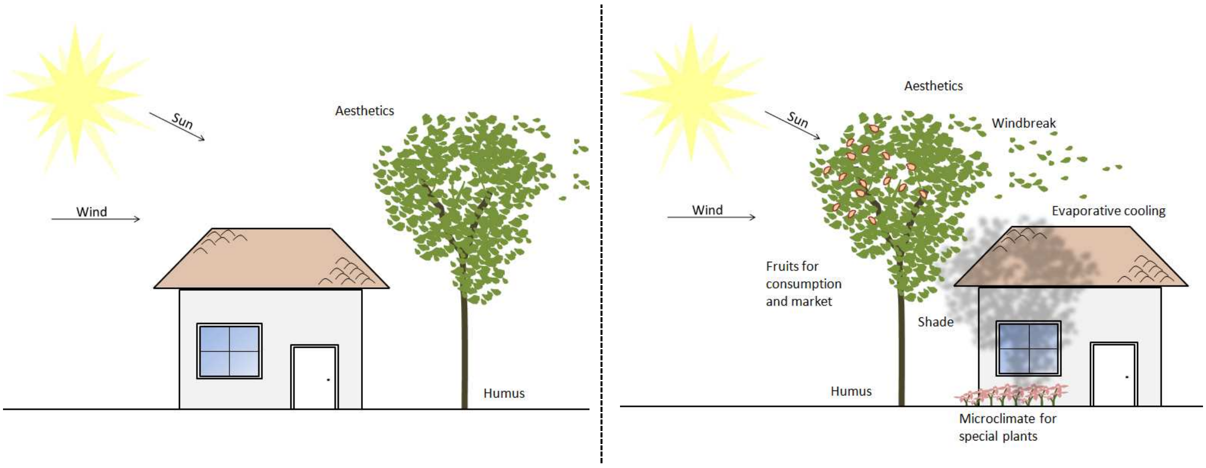


Figure 76: Illustration: increased system productivity due to interactions between natural and human systems using simple design principles.

Now, one could imagine many more functions for the same single tree in the figure like building a natural fence, support for vine plants and a tree house in the crown for children to play without any function reducing the importance of other functions. Alternatively, if the tree cannot fulfill these functions (left side), they will have to be fulfilled by external investments (buy more food, air conditioning, travel to other places for relaxing etc.).

As seen in the results of this research, the households already keep perennial crops and fruit trees in their home gardens, even if commercial interest is not directly pursued. Fallow land areas offer a realistic potential for such systems to be expanded. With the right design technique, a higher and more stable productivity is possible, especially to produce services of primary importance for urban areas such as cooling effect, socialization, food production for the poor and beauty. The simple principle of giving each element in the open space as much functions as possible while planning can be transmitted to any person that manages any type of open space. Following this logic, more functions, interactions and complexity of open spaces will naturally tend to store the highest possible amounts of carbon, pushing up the agroclimax stage (defined in chapter 5.5), increasing V_{eco}, V_{bio}, C_i, R_i and biodiversity.

The results of chapter 5.3 show that the analyzed recreation area systems can develop a high V_{eco} and at the same time a high V_{bio}, resulting in a high resilience index (R_i) and more diversity. A high V_{eco} can also potentialize the direct interactions between the natural and human systems, increasing the resilience of the overall urban system. Figure 77 illustrates in a simplified way these interactions. By increasing the V_{eco} of an open space, the very direct positive effects of shading, cooling and wind breaking can be felt by two households instead of one.

Figure 77: Illustration: importance of Veco to the interactions between natural and human/urban systems.

People and their housings expand vertically in the form of tall buildings and skyscrapers, on the same limited area, colonizing a higher volume in space. The planning and design of open spaces, delimited in their area as well, fairly should follow the same three dimensional approaches if a balance between both is pursued.

The land use systems applied to open spaces in this research are distinguished according to their primary function. The perennial crop system has a primary function of providing food and increase the subsistence especially at poor households. Recreation area systems provide beauty and relaxing as well in public areas and in private households. Analyzing the similar C_i of both systems (Figure 32) and V_{eco} (Figure 31) it is possible to assume that theoretically the perennial crop systems can hold the proportions between space occupied by plants and space free for transit under the canopy that are necessary to fulfill the aesthetic functions of recreation areas.

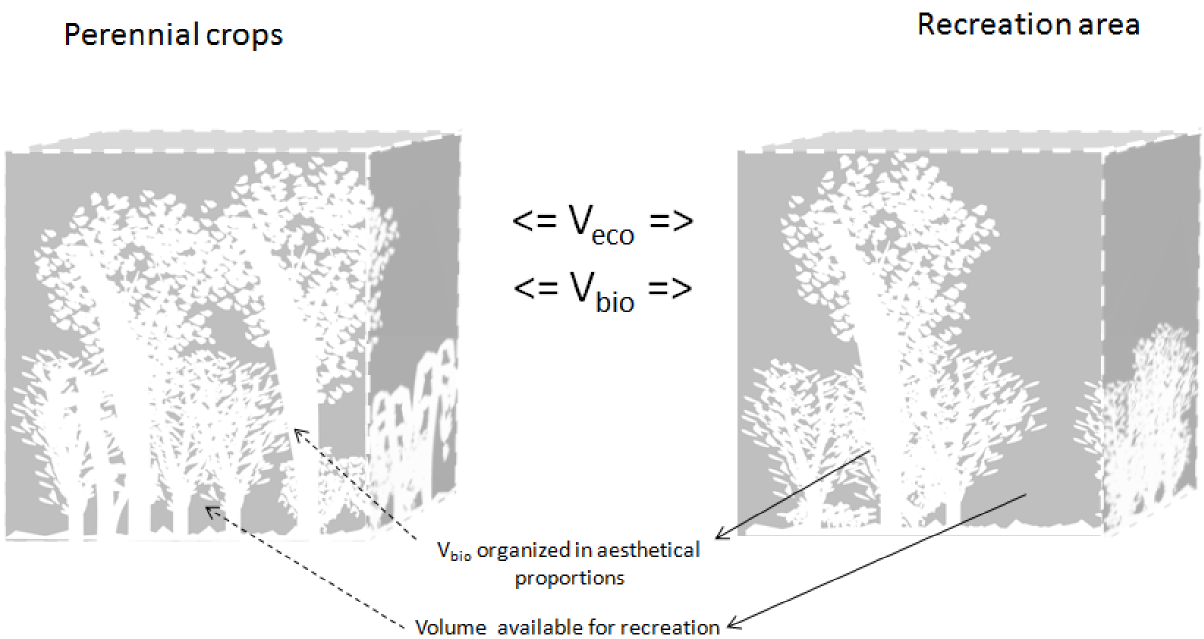


Figure 78: Illustration: V_{bio} as an indicator for the potential multifunctionality of open spaces.

Figure 79 illustrates the potential increase of the direct functionality of those systems if perennial crop systems are designed to provide recreation and aesthetics or if recreation area systems are designed using productive crops.

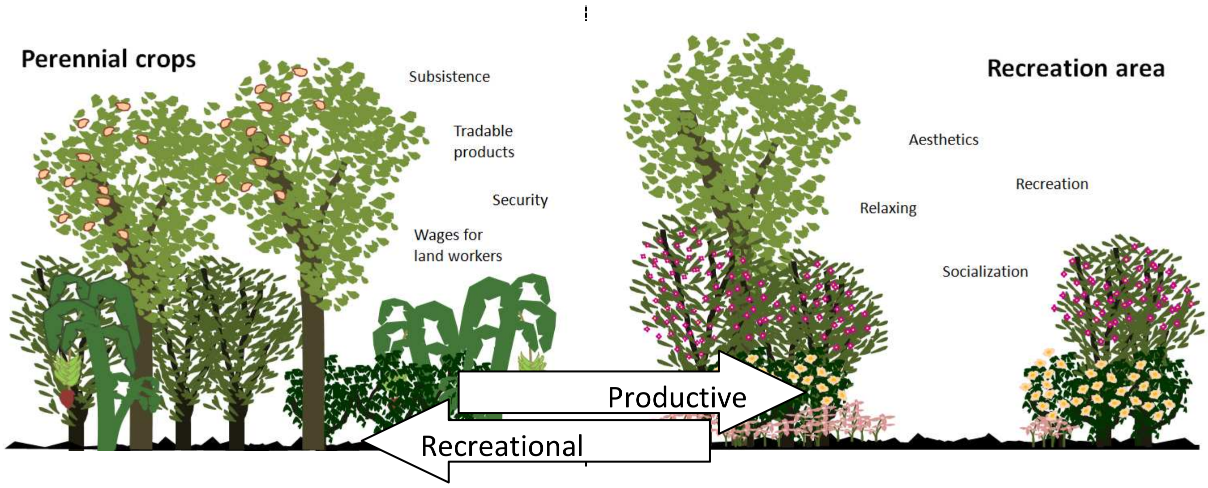


Figure 79: Illustration: Increasing functionality of open spaces while maintaining V_{eco} and C_i.

Off course the acceptance of such multifunctional use of open spaces has to be tested since fruit trees also can produce waste (decomposing fruits) or have other negative impacts like attract too many birds (noise) or provide less aesthetic values that could reduce the function of relaxing for example. In this sense, the potential tradeoffs would have to be quantified and balanced from case to case during the planning process of open spaces. The emergy methodology described in chapter 7.3 considers all these aspects as long the subjective values are considered. Another point to be analyzed (site specific) is if the reduced area of urban open spaces and their exposure to urban pollution provides enough qualitative and productive potential to be of interest for the people meant to harvest them, either for consumption or for the market.

Table 20 shows that in the peri-urban fringe of Recife plenty of space is still open and offers a potential for implementing multifunctional land use systems. Analogue to Figure 76 that shows the potential increase of interactions between natural and social systems by placing one single element (in this case a tree) at the right place, Figure 80 shows how a whole land use system can increase the interactions between rural and urban systems.

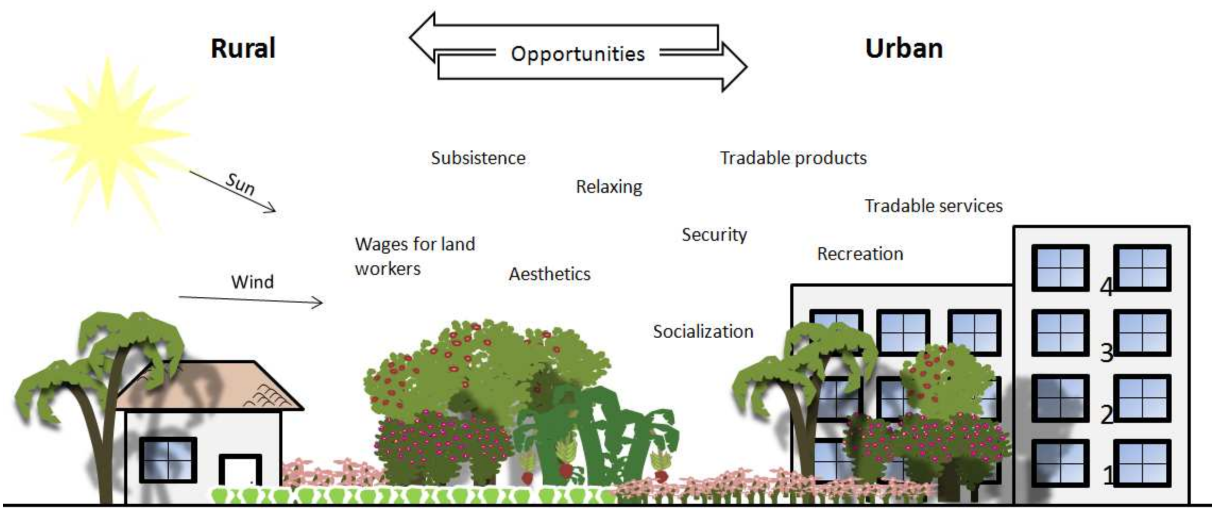


Figure 80: Illustration: Improved rural/urban system interaction by designing multifunctional open spaces in the peri urban fringe

In the peri urban area of Recife analyzed, 13% of the land is covered by fallow land systems and only 1% is sealed, not much if compared to the most urbanized of the areas (area-III, Apipucos) that has 39% of the land fallow and 23% sealed by housings.

Assuming area-III as a reference for a stable urban area with defined infrastructure, land tenure and socio-economic profile, not susceptible to further uncontrolled (not planned) changes, it is possible to delimit the area where the opportunity space matches the decision space (Figure 75) at the household level. Further it is possible to draw an alternative carbon stock scenario for an urban neighborhood if capacity building is focused in the peri urban fringe of Recife.

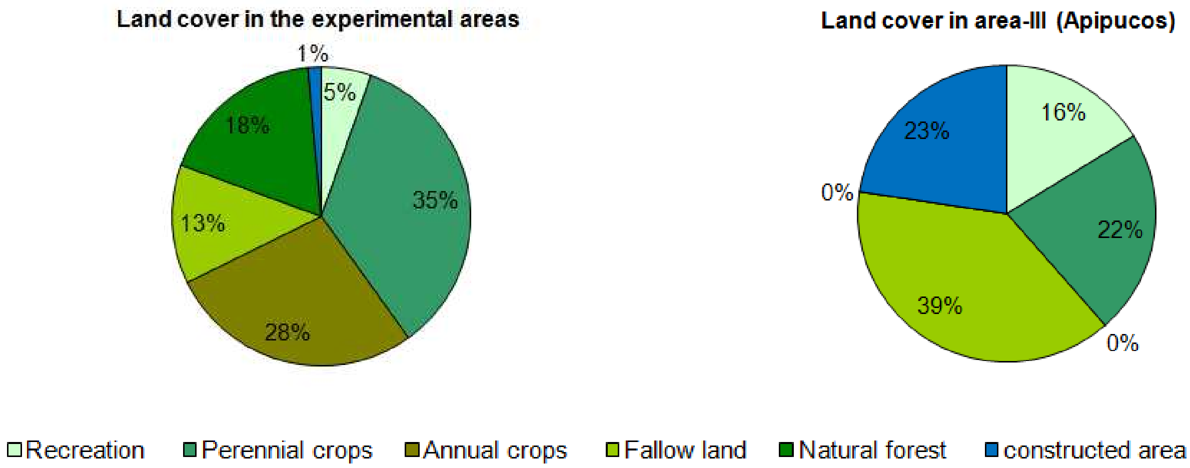


Figure 81: Land cover in the peri urban area of Recife compared to area-III (Apipucos).

The first assumption is that natural forest systems (fragments) are protected by law and the 18% of the land covered by them will be maintained as reservoirs. The second assumption is that housings will increase the sealed area up to 23% of the total land cover while the urban population increases. These assumptions implicate in a reduction of the decision space at the household level to change land use.

Figure 81 shows that the perennial crops together with recreation area systems are maintained after the urbanization but recreation areas gain in relative importance while perennial crops have their importance reduced. A pro-active planning approach has to consider this changing importance of different land use systems on the household level that will happen along the urbanization process what reduces the opportunity space for land use change. This means that 11% of the area in the peri urban fringe of Recife has to face a functional change from purely perennial crop systems to supply recreational functions as well, demanded by the urbanization process. Figure 82 shows a possible land cover distribution that could endure the interest conflicts illustrated in Figure 74.

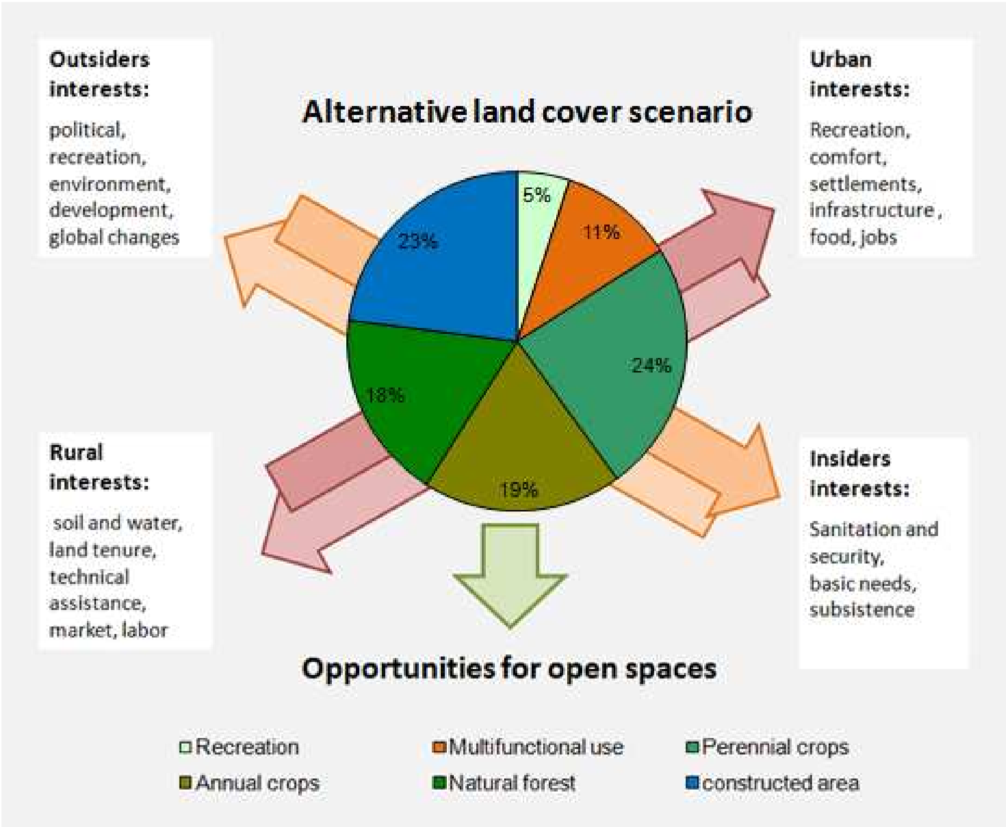


Figure 82: Alternative land cover scenario in the peri urban fringe of Recife.

The area covered by annual crops would be reduced from 28 to 18% and for the economical viability this area would have to be protected from fragmentation and the lost income provided has to be compensated by technical improvement through capacity building, agronomic assistance and financial services. The overall carbon stocks in this simulation would increase from 14.02 to 29.64 t/ha while attending the demanded functions of open spaces in a neighborhood like Apipucos (area-III). The carbon stocks found in the complete study area (26.64 t/ha) would be maintained and even improved while a part of the area is build up in the urbanization process.

8 CONCLUSIONS

The land use systems found in the peri-urban fringe of Recife are determined by their direct function to the settlers that manage them. The huge diversity of financial, legal and educational possibilities is reflected on the variety of land uses on a household level. Those range from natural forest fragments through annual and perennial crop systems up to very urban forms like recreation areas, street trees and fallow land. All are found side by side in the study area. Changing interests can affect not only the change between those land use systems but their existence as well.

The implications on carbon stocks and environment of such changes were analyzed and evaluated. The structural and productive parameters undergo a huge variation across the experimental systems. The evaluation on a common methodological pathway, in this case the biomass assessment and the three dimensional approach using V_{eco} and V_{bio} as a starting point, could enable a clear comparison between those. Important indicators could be created to support decision making regarding the ecological implications of land use change in the peri-urban fringe of Recife. The specific questions formulated in four hypotheses in chapter 2 will be answered as follows:

Hypothesis-1: *While urban recreation areas fulfill functions as social networking, recreation, relaxing and aesthetics, they can also store at least as much carbon as urban forest fragments.*

The forest fragments analyzed in this research (natural forest system) store 48.33 t/ha of carbon, almost twice as much as the recreation area systems that store 24.23 t/ha. A direct carbon stock compensation would only be possible with a doubling of the area what would be adverse to the urbanization process. Moreover the forest fragments are not in fact in an eco-climax stage where GPP = NPP and expected to undergo a biomass increase along time what adds a conservative view to this results. Nevertheless the recreation area systems have a higher resilience index (R_i) than the forest fragments (206 and 156 respectively) determined by the very large basal area of individual trees. The species richness is higher as well (62 and 43 respectively), thus enabling a compensation of other ecological implications.

Hypothesis-2: *Annual crops, which are often produced under informal land tenure conditions store at least as much carbon as if the land tenure is formal but kept fallow.*

In fact annual crop systems store 0.90 t of carbon per ha and fallow land systems store 33.48 t/ha. In the fallow land system up to 32.08 t/ha are stored in 61.2 trees of strata 2, 3 and 4. Those are leftovers from former farm trees or plantations while the annual crop system is composed only by strata-1 including litter. If those trees are not considered, fallow land systems still store more carbon in strata-1 including litter, presenting a similar biomass distribution like the perennial crop system while this strata is very simplified in the annual crop system, reduced to dicots (80.2%), some fine litter(16.3%) and very reduced coarse litter (3.5%). Yet, with an intensive rotation of the annual crops, the carbon fixation rate is the highest in this system (10.34 t/ha/y), being 91.3% exported after harvest, thus the carbon stocks being maintained artificially low in a context of high productivity.

Hypothesis-3: *The loss of arable land in urbanizing areas and consequently the reduction of biomass and carbon stocks on a hectare basis can be compensated by a higher crowding intensity in the land use systems applied to smaller urban backyards, meaning that the loss of biomass per unit of area is compensated by a higher biomass per unit of volume.*

Experimental area-III (Apipucos) is considered as the most urbanized neighborhood due to the smallest plot size (0.08 ha), the highest build-up area (23%) and the general socio economical character meaning a higher degree of formalized land tenure, higher income per household (1091.88 BRA) generated by urban jobs not related to agriculture. The open space alone is partitioned in 21% recreation area, 29% perennial crops with no income generating character and 50% fallow land. Since the survey was done inside defined households (small private plots), fallow land is not expected to be traded or build-up. Including the build-up parts this area stores 14.02 t/ha of carbon in a V_{eco} of 22.49% from V_{pot} and a C_i of 0.19%. Both, V_{eco} and C_i, very low if compared to the overall mean across all areas (69.83 and 0.26% respectively). A compensation of the carbon stocks is only possible if the fallow land area is converted to other land use systems. Considering the direct functions and the importance given to different systems across the study area, a distribution of 23% build-up, 18% natural forest, 24% perennial crops, 19% annual crops and 16% recreation area could compensate the carbon stocks reduced during the urbanization process. In this simulated scenario carbon stocks could be compensated only to a degree of 23% build-up area. Any further reduction of open space would implicate in a compromise of functions to the settlers and/or carbon stocks.

Hypothesis-4: *Under pressure of demographic growth the management of open spaces tends to intensify while the available area is reduced, resulting in relatively less fallow land if compared to less densely populated areas.*

Assuming the household level to be the smallest management unit defining open spaces, the most densely populated area analyzed in this research is area-III with 50 people living on one ha. Each person has 154.70 m² of open space available. Fallow land use systems represent 50% of this area, almost four times more than the mean across the study areas of 13.07%. In the less urbanized areas with low population densities and a low degree of build-up area, open spaces fulfill income generating functions such as the production of annual and perennial crops, creating job opportunities and assuming a livelihood character for the settlers. Even if the forest fragments found in that areas are considered as "not directly providing income nor jobs" and thus added to the fallow land area, both together will represent 31.3% of the total open space across the study areas while in the urbanized area-III this proportion will be maintained at 50% since there are no natural forest systems (fragments) on the household level. Nevertheless the ecological implications of the natural forest systems and their role in stabilizing cropping systems have to be considered.

9 LIST OF REFERENCES

ADELL, G., 1999; Theories and models of the peri-urban interface: A changing conceptual landscape. Development planning unit, University college, London.

ALLEN et al., 1999. Environmental Problems and Opportunities of the Peri-urban Interface and their impact upon the Poor. Peri-urban Research Project Team, Development Planning Unit. University College London.

ALLEN, A., 2001. Environmental Planning and Management of the Periurban Interface. Key note Paper for the Conference Rural-Urban Encounters: Managing the Environment of the Periurban interface, London 9-10 November 2001.

ALLEN, T., 2003. Environmental planning and management of the peri-urban interface: perspectives on an emerging field. Development planning unit, University college, London.

ANDRADE, K.V.S.A.; RODAL, M.J.N., 2004. Fisionomia e estrutura de um remanescente de floresta estacional semidecidual de terras baixas no nordeste do Brasil. Revista Brasil. Bot., V.27, n.3, pp.463-474.

BAILKEY, M. and NASR, J., 2000. From Brownfields to Greenfields: Producing Food in North American Cities. Community Food Security News.

BARLOW, J.; HARMAN, I. and BELCHER, S., 2004. Scalar fluxes from urban street canyons. Part I: Laboratory simulation. Boundary Layer Meteorology, 113, 369-385

BAUMERT, S.E., 2008. Charakterisierung der agrarischen Landnutzungssysteme in Ketou, Benin. Diplomarbeit der Landwirtschaftlichen Fakultät der Rheinischen Friedrich-Wilhelms-Universität zu Bonn.

BBC WEATHER. Available from: http://news.bbc.co.uk/weather/

BENDAVID-VAL, A., 1989. Rural-urban linkages : farming and farm households in regional and town economies. Review of Urban and Regional Development Studies, Vol. 1, No. 2 (July 1989) p. 89-97.

BETTS, R., 2004. Met Office's Hadley Centre for Climate Prediction. New Scientists, Climate change. Available from: www.newscientist.com/channel/earth/climate-change/dn6017

BROWN M. T.; ULGIATI S., 2004. Energy Quality, Emergy, and Transformity: H.T. Odum's contribution to quantifying and understanding systems. In: Ecodinamica - Bioligi Italiani, May 2004.

BROWN, C.J.; FULTON, E.A.; HOBDAY, A.J., MATEAR, R.J.; POSSINGHAM, H.P.; BULMAN, C.; CHRISTENSEN, V.; FORREST, R.E.; GEHRKE, P.C.; GRIBBLE, N.A.; GRIFFITHS, S.P.; LOZANO-MONTES, H.; MARTIN, J.M.; METCALF, S.; OKEY, T.A.; WATSON, R. AND RICHARDSON, A.J. 2010. Effects of Climate-driven Primary Production Change on Marine Food Webs: Implications for Fisheries and Conservation. Global Change Biology 16: 1194-1212.

BROWN, F.; MARTINELLI, L.A.; WAYT THOMAS, W.; MOREIRA, M. Z.; CID FERREIRA, C. A.; VICTORIA, R. A., 1995. Uncertanty in the biomass of Amazonian forest: an example from Rondonia, Brazil. Forest Ecology and Management 75: 175-189.

BROWN, M.T. and ULGIATI, S., 1997. Emergy Based Indices and Ratios to Evaluate Sustainability: Monitoring technology and economies toward environmentally sound innovation. Ecological Engineering 9:51-69.

BROWN, M.T. and ULGIATI, S., 1999. Emergy Evaluation of the Biosphere and Natural Capital. Ambio 28, vol. 6, pp.486-493.

BRUNDTLAND REPORT, 1987. Our Common Future, Report of the World Commission on Environment and Development. World Commission on Environment and Development, 1987. Published as Annex to General Assembly document A/42/427, Development and International Co-operation: Environment August 2, 1987. Retrieved, 2007.11.14.

CANDIDO C.; DEAR R. J.; BITTENCOURT L.; LAMBERTS R., 2010. Air movement acceptability limits and thermal comfort in Brazil's hot humid climate zone. Building and Environment, 45(1)(222-229).

CARSLAW, D.C. AND BEEVERS, S. D., 2004. Investigating the potential importance of primary NO2 emissions in a street canyon. Atmospheric Environment, 38, 3585-3594.

CASTRO, J., 1948. Fatôres de Localização da Cidade do Recife. Um ensaio de Geografia. Rio de Janeiro; Imprensa Nacional; 1948. 84 p. ilus, mapas.

CERNUSAK L.A., 2007. Large variation in whole-plant water-use efficiency among tropical tree species. Smithsonian Tropical Research Institute, New Phytologist (2007) 173 : 294 –305.

CHAPIN et al., 2008. Changing feedbacks in the climate-biosphere system. Frontiers in the Ecology and Environment 6(6), 313-320.

CHOI, D. and LEE, B., 2006. Analysis of Passive Cooling Effect of the Tree by Field Observation in the Summer. Journal of the Korean solar Energy Society, Vol.26, No.4, pp.109-118.

COMMISSION ON CLIMATE CHANGE AND DEVELOPEMENT, 2009. Closing the Gaps: Disaster risk reduction and adaptation to climate change in developing coutries. Ministry of foreign affairs, Sweden.

CONSUMER ENERGY CENTER, 2011. Evaporatibe cooling: How an evaporative cooler works. California Energy Comission. http://www.consumerenergycenter.org/home/heating_cooling/evaporative.html

COY, M. and KRAAS, F., 2003. Probleme der Urbanisierung in den Entwicklungsländern. Petermanns Geographische Mitteilungen, 147 (1), S. 32-41.

CRAVEN, 2009. What's the Worst That Could Happen? A Rational Response to the Climate Change Debate. Pedigree trade, 264 p.

CURE, 2007. PLUREL: Peri-urban Land Use Relationships: Strategies and Sustainability Assessment Tools for Urban – Rural Linkages. University of Manchester. Centre for Urban Regional Ecology (CURE). Available from: http://www.sed.manchester.ac.uk/research/cure/research/plurel/

DEWI, S.; KHASANAH, N.; RAHAYU, S.; EKADINATA A.; AND VAN NOORDWIJK, M., 2009. Carbon
Footprint of Indonesian Palm Oil Production: a Pilot Study. World Agroforestry Centre - ICRAF, SEA Regional Office. Bogor, Indonesia.

DICKINSON, R.E. and HENDERSON-SELLERS, A., 1988. Modelling tropical deforestation: A study of GCM land-surface parametrizations. Quarterly Journal of the Royal Meteorological Society, 114: 439–462. doi: 10.1002/qj.49711448009

DULAC, 2005. Recicling urban organic wastes in agriculture. In: RUAF, 2005. Resource centre on urban agriculture and forestry. Book-Annotated bibliography on urban agriculture, www.ruaf.com

DUNNET N. and KINGSBURY N., 2004. Planting green roofs and living walls. Timber Press, Inc. Portland, OR.

DUPONT, S.; OTTE, T. L.; HING, J.K.S., 2004. Simulation of meteorological fields within and above urban and rural canopies with a mesoscale model (MM5). Boundary-Layer Meteorology, 113, 111-158.

EISENHOUR et. al., 2006. Integrated Principals of Zoology. McGraw Hill. pgs 815-818.

ELSA F.B., 2011. The urban heat isles and the micro-climatic variations brought about by vegetation. Available from: http://www.mybestlife.com/eng_bio/bio-architecture /Urban_vegetation.htm.

EMPRAPA, 2007. Empresa Brasileira de Pesquisa Agropecuária. Banco de dados climáticos do Brasil. Available from: http://www.bdclima.cnpm.embrapa.br/resultados/ balanco.php?UF=&COD=145.

ENGINEERING TOOLBOX, 2011. Available from: http://www.engineeringtoolbox.com/ water-thermal-properties-d_162.html

ERMECKE, 2009. Rettung vor den Klimarettern, gibt es die Gefahr für das Weltklima? KE Research, Die Andersdenker.

FAO, 2005. Farming in urban areas can boost food security, green the cities through agriculture. World Environment Day. Available from: http://www.fao.org /newsroom/en/news/2005/102877/index.html.

FAO, 2009. Follow-up to the high level conference on world food security: FAO contribution to the implementation of the comprehensive framework for action. Document for FAO council, Rome.

FSI, 1988. The state of Forest Report 1987. Forest Survey of India; Ministry of Environment & Forests, Govt. of India.

GAMA-RODRIGUES, A.; BARROS, N.; COMERFORD, N., 2007. Biomass and nutrient cycling in pure and mixed stands of native tree species in southeastern Bahia, Brazil. Rev. Bras. Ciênc. Solo. vol.31, n.2 , pp. 287-298 . Available from: <http://www.scielo.br/scielo.php?script=sci_arttext&pid=S0100-06832007000 200011&lng=en&nrm=iso>. ISSN 0100-0683. doi: 10.1590/S0100-06832007000200011.

GCP, 2010. Ten Years of Advancing Knowledge on the Global Carbon Cycle and its Management. Tsukuba: Global Carbon Project

GOLDEWIJK, K. and BEUSEN, A., 2010. Long-term dynamic modeling of global population and built-up area in a spatially explicit way: HYDE 3.1. Article first published online : 10 SEP 2010, DOI: 10.1111/j.1466-8238.2010.00587.x.

GOMES, J. C., 2003. Cultivo da Mandioca para a Região dos Tabuleiros Costeiros. Embrapa, Mandioca e fruticultura. Available from: http://sistemasdeproducao.cnptia. embrapa.br / FontesHTML/Mandioca /mandioca_tabcosteiros.

GREENIDGE, C. B., 1999. Growing Cities Growing Food. Urban agriculture on the Policy Agenda. Results of an international workshop in Havana, Cuba.

HAIRAH, K. S. M.; SITOMPUL, M. V.; NOORDWIJK; PALM, C., 2001. Methods for sampling carbon stocks above and below ground. ICRAF, ASB lecture note 4b. Available from: http://www.icraf.cgiar.org/sea, 2005.

HALLDIN, M., 2006. Chart: Intertropical conversion zone. Available from: http://en.wikipedia.org/ wiki/File:ITCZ_january-july.png.

HALTINER, G.J.; WILLIAMS, R.T., 1980. Numerical Prediction And Dynamic Meteorology. IE-Wiley.

HANSEN et al., 2006. Global temperature change. Proceedings of the National Academy of Sciences, 103, 14288-14293.

HARDEE, K.; MOGELGAARD, K.; YOUNG, M.H., 2009. Projecting Population, Projecting Climate Change: Population in IPCC Scenarios. PAI Working Paper, Population Action International.

HAYEK, U.; HALATSCH, J.; KUNZE, A.; SCHMITT, G.; GRÊT-REGAMEY, A.; 2010. Integrating Natural Resource Indicators into Procedural Visualisation for Sustainable Urban Green Space Design.

HOFFMANN, D., 1995. Die Welt ist Stadt. Aktuelle Entwicklungen und Tendenzen der Urbanisierung. In: GROHMANN, P. et al., 1995. Andere Städte, anderes Leben: Stadtentwicklung, Umweltkrise und Selbsthilfe in Afrika, Asien und Lateinamerika. Saarbrücken, S. 17-38.

HOPKINS, A.S., SCHELLNHUBER, H.J.; 2005. Urbanised Territories as a Specific Component of the Global Carbon Cycle. PIK-report n° 94; Potsdam institute for climate impact research.

HOWDEN et al., 2007. Adapting agriculture to climate change. Proceedings of the National Academy of Sciences 104, 19691-19696.

HUANG S., CHEN C., 2005. Theory of urban energetics and mechanisms of urban development. Graduate Institute of Urban Planning, National Taipei University. Taipei, Taiwan 10433. Elsevier, ecological modelling.

IBGE. Instituto brasileiro de geografia e estatistica. Available from: http://www.ibge.gov.br/home.

IHOPE, 2010. Developing an Integrated History and Future of People on Earth (IHOPE): Research Plan. IGBP Report No. 59. IGBP Secretariat, Stockholm. 40pp.

INTERNATIONAL ASSOCIATION FOR URBAN CLIMATE. Available from: http://www.urban-climate.org/

IPCC, 2007. Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Pachauri, R. K. and Reisinger, A. IPCC: Geneva, Switzerland.

JANSSENS, M.J.J., DENG, Z., SONWA, D., TORRICO, J.C., MULINDABIGWI, V. AND POHLAN, J. 2006. Relating Agro-climax of Orchards to Eco-climax of Natural Vegetation. Acta Hort. (ISHS) 707:181-186. Available from: http://www.actahort.org/books/707/707_22.htm

JANSSENS, M.J.J., MULINDABIGWI, V., POHLAN, J., TORRICO, J.C., 2004. Eco-Volume and bio-surface interplay with the universal scaling laws both in biology and in the Mata Atlantica. Seminario A Cooperacao Brasil-Alemanha no Programa mata Atlantica. Teresopolis, 29 November, 3 December 2004.

JANSSENS, M.J.J., POHLAN, J., KEUTGEN, N. & TORRICO, J.C., 2009. Plants are not weight watchers but space invaders. In: Technology, Resource Management & Development Volume No. 6 – Special issue in Honor of Prof. Dr. Hartmut Gaese. Technology and Resource Management in the Tropics and Subtropics – State of the Art and Future Prospects. Fachhochschule Köln, Institute for technology and Resources in the tropics and Subtropics, Cologne, Germany. Pp.115-122.

JENDE, O., 2005. The conversion process of Chiapas coffee plantations through Agroforestry into timber production and its ecological implications. Master thesis, University of Bonn, Institut für Gartenbauwissenschaft, Bonn, Germany.

KEELING et al., 2005. Atmospheric CO2 records from sites in the SIO air sampling network. In Trends: A Compendium of Data on Global Change. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A.

KIM, J.; BAIK, J., 2010. Effects of street-bottom and building-roof heating on flow in three-dimensional street canyons. In: Advances in Atmospheric Sciences, 27:3(513--527).

KITCHING, R.L., 1983. Systems ecology, University of Queensland Press, 1983.

KLEIN, R.J.T.; SCHIPPER, E.L.F. and DESSAI, S., 2005. Integrating mitigation and adaptation into climate and development policy: three research questions. Environmental Science & Policy 8(6): 579–588. In: Bruno Locatelli, Vanessa Evans, Andrew Wardell, Angela Andrade, Raffaele Vignola, 2010. Forests and climate change in Latin America, Linking adaptation and mitigation in projects and policies. CIFOR, brief info, No. 31, November 2010. www.cifor.cgiar.org

KOBASHI, T.; SEVERINGHAUS, J.M.; BARNOLA, K.; KAWAMURA, T.; CARTER; NAKAEGAWA, T., 2010. Persistent multi-decadal Greenland temperature fluctuation through the last millennium. Climatic Change, 100, 733–756.

KOERICH, W.D., 2010. A Evolucao do Uso da Laje Jardim. Faculdade Assis Gurgasz. Curso de Arquitetura e Urbanismo. Cascavel, Brazil.

KÖHLER, M. and KEELEY, M., 2005. The green roof tradition in Germany: The example of Berlin. In Hoffman, L. & W. McDonough (eds.), Ecological Design and Construction. Earthpledge, New York. Pp. 108–112.

LATOKA, A. J., 1922. Contribution to the energetics of evolution. School of Hygiene and Public Health. Johns Hopkins University.

LEITÃO FILHO, H.F., 1994. Diversity of Arboreal Species in Atlantic Rain Forest, An. Acad. bras. Ci., 66 (Supl. 1).

LEUZZI, G., MONTI, P., AMICARELLI, A., 2010. An urban scale model for pollutant dispersion in Rome. International Journal of Environment and Pollution (IJEP), Volume 40 - Issue 1/2/3 - 2010.

LI, D., 2007. EMergy Evaluation: a Multi-Scale Optimum Tool for Visioning Sustainability. 43rd ISOCARP Congress 2007.

LOCATELLI, B.; EVANS, V.; WARDELL, A.; ANDRADE, A.; VIGNOLA, R., 2010. Forests and climate change in Latin America, Linking adaptation and mitigation in projects and policies. CIFOR, brief info, No. 31, November 2010. www.cifor.cgiar.org

MACHADO, I.C.; LOPES, A.V.; PÔRTO, K. C.; GUEDES, M.L.S., 1998. Reserva Ecológica de Dois Irmãos: Estudos em um Remanescente de Mata Atlântica em Área Urbana (Recife-Pernambuco-Brasil). Editora Universitária UFPE, Recife.

MARSHALL, F.; WALDMAN, L.; MACGREGOR, H.; MEHTA, L. and RANDHAWA, P., 2009. On the Edge of Sustainability: Perspectives on Peri-urban Dynamics. STEPS Working Paper 35, Brighton: STEPS Centre.

MASLANIK, J.; FOWLER, A.C.; STROEVE, J.; DROBOT, S.; ZWALLY, J.; YI, D. and EMERY, W., 2007. A younger, thinner Arctic ice cover: Increased potential for rapid, extensive sea-ice loss. Geophysical Research Letters 34, L24501.

MAYER, P. H., 2009. Fertilidade do Sistema Agrícola: Estudo em três Comunidades da Região Metropolitana de Curitiba- PR. PhD Thesis. Universidade federal do Parana, Curitiba.

M'BAREK, R.; BEHLE, C.; MULINDABIGWI, V.; SCHOPP, M.; SINGER, U., 2005. Sustainable resource management in Benin embedded in the process of decentralisation. Physics and Chemistry of the Earth 30, 365-371.

Mc MULLEN, 2009; Climate change science compendium; United nations environment programme.

MERTINS, G., 2006. Wachsende Marginalisierung und Marginalviertel in Großstädten der Dritten Welt. In: GANS, P. et al. (Hrsg.): Kulturgeographie der Stadt. Kiel (Kieler Geographische
Schriften 111). S. 63-77.

MLOZI, M.R.S., LUPANGA, I.J., MVENA, Z.S.K., 1992. Urban agriculture as a survival strategies in Tanzania. In: Baker J. & Pedersen P.O. (eds). The rural-urban interface in Africa: expansion and adaptation; seminar proceedings no. 27. Uppsala: Nordiska Afrikainstitutet (The Scandinavian Institute of African Studies). pp. 284-294.

MOLLISON B. C., 1988. Permaculture: A Designers`Manual. Tagari Publications.

MONEO, 2010. Der Beitrag der Landwirtschaft zu den Treibhausgasen. Environmental Science Published for Everybody Round the Earth. Available from: www.atmosphere.mpg.de

MONTAGNINI, F. and NAIR, P.K.R., 2004. Carbon sequestration: and underexploited environmental benefit of agroforestry systems. Agroforestry Systems 61, 281-295. In: Trumper, K., Bertzky, M., Dickson, B., van der Heijden, G., Jenkins, M., Manning, P., 2009. The Natural Fix? The role of ecosystems in climate mitigation. A UNEP rapid response assessment. United Nations Environment Programme, UNEPWCMC, Cambridge, UK

MYERS, N.; MITTERMEIER, R.A.; MITTERMEIER, C.G.; DA FONSECA, G.A.B.; KENT J., 2000. Biodiversity hotspots for conservation priorities. Nature 403, pp. 853-858.

NEHREN, S.A., 2006. Bestandsaufnahme zur Situation im Untersuchungsgebiet Mata Dois Irmãos Recife- Brasilien. Infoblatt innerhalb des Projektes „Open Spaces in emerging
Megacities - Potetial for nature orientated living“.

NELLEMANN, C.; MACDEVETTE, M.; MANDERS, T.; EICKHOUT, B.; SVIHUS, B.; PRINS, A.G.; KALTENBORN, B.P.,2009. The environmental food crisis – The environment’s role in averting future food crises. A UNEP rapid response assessment. United Nations Environment Programme, GRID-Arendal, www.grida.no.

ODUM, E.P., 1971. Fundamentals of ecology (3rd ed.) Saunders, Philadelphia.

ODUM, H.T., 1996. Environmental Accounting: Emergy and Environmental Policy Making. John Wiley and Sons, New York. P370.

OFFICIAL WEBSITE OF VINHEDO, 2009. Prefeito Milton Serafin recebe Premio nacional do Instituto Biosfera from 21.05.2009. Available from: http://www.vinhedo.sp.gov.br /noticia.php?id=192

ONMURA S.; MATSUMOTO M.; HOKOI S., 2001. Study on evaporative cooling effect of roof lawn gardens. Energy and Buildings, 33 (7), pp. 653-666.

PATWARDAN, A.; WARRAN, A.; 2005. Carbon sequestration potential in and around Pune city. RANWA, C-26/1; Ketan Heights, Kothrud, Pune, 411038, India.

PENMAN, J.; GYTARSKY, M.; HIRAISHI, T.; KRUG, T.; KRUGER, D.; PIPATTI, R.; BUENDIA, L.; MIWA, K.; NGARA, T.; TANABE, K.; WAGNER, F., 2003. In: Good Practice Guidance for Land Use, Land Use Change and Forestry. Institute for Global Environmental Strategies, Kanagawa.

PLANO DIRETOR RECIFE, 2005. A dinamica fisico territorial, Diagnostico. Available from: http://www.recife.pe.gov.br/pr/secplanejamento/planodiretor/diagnostico_ii.html

POHLAN, H. A. J.; TOLEDO TOLEDO, E.; LEYVA GALÁN, A.; MARROQUÍN AGREDA, F., 2005. Manejo agroecológico de la caña de azúcar (Saccharum spp.) en el Soconusco, Chiapas, México. III Congresso Brasileiro de Agroecologia, 17 a 20 de Outubro de 2005 – Florianópolis/SC, CD memorias orais, pdf 072.

POHLAN, J.; SOTO, L.; BARRERA, J., 2006. El cafetal del futuro: Realidades y Visiones. Aachen, Shaker Verlag, 2006, 478 paginas. ISBN 3-8322-5052-2.

POTERE D. and SCHNEIDER A., 2007. A critical look at representations of urban areas in global maps. Geojournal 69 (1-2): 55-80. In: Nellemann, C., MacDevette, M., Manders, T., Eickhout, B., Svihus, B., Prins, A. G., Kaltenborn, B. P. (Eds). February 2009. The environmental food crisis – The environment's role in averting future food crises. A UNEP rapid response assessment. United Nations Environment Programme, GRID-Arendal, www.grida.no.

RABINOVITCH, J., 2001. Key note Paper for the Conference Rural-Urban Encounters: Managing the Environment of the Periurban interface, London 9-10 November 2001.

RAMANATHAN, 2008. On avoiding dangerous anthropogenic interference with the climate system: Formidable challenges ahead. Proceedings of the National Academy of Sciences 105(38), 14245-14250.

RANTA, P.; BLOM, T.; NIEMELÄ, J.; JOENSUU, E.; SIITONEN, M., 1998. The fragmented Atlantic rain forest of Brazil-size, shape and distribution of forest fragments. Biodiversity and Conservation 7, pp. 385-403.

RIVERA, J.; H. LOSADA, N.; WOODGATE, G. and WOODGATE, M., 2001. The Spatial Distribution of Agricultural Activities in the Mountains Southeast of Mexico City. Paper prepared for the DPU International Conference: Rural-Urban Encounters: Managing the Environment of the Peri- Urban Interface, London 9-10 November 2001 Imperial College at Wye, England / Universidad Autonoma Metropolitana.

ROBITU, M.; MUSY, M.; INARD, C.; GROLEAU, D., 2008. Modeling the influence of vegetation and water pond on urban microclimate. Solar Energy, 80 (4), pp. 435-447.

RUAF, 2009. Cities, Food and Agriculture: Challenges and the Way Forward. Discussion Paper for the Technical Consultation "Agriculture, Food and Cities", Rome.

RUMBARTIS del RIO, 2009. Cities Climate Change Resilience and Urban Agriculture. Strategic Partnership Meeting on Urban Agriculture. IDRC, Marseille.

SAFONOV, P.; COMAR, V.; ORTEGA, E., 1999. Energy and Emergy Based Dynamic Modeling of Brazil: Conceptual Considerations and Scenarios for Sustainable Development. In: Introduction to Ecological Engineering with Brazilian Case Studies, Ortega E., Safonov P., Comar V. (eds), UNICAMP, Campinas.

SAKMOND, 2005. Bibliography of urban climate. World meteorological organization. Available from: http://www.urban-climate.org/resources_fr.htm

SCHLESINGER, W.H., 1991. Biogeochemistry, an Analysis of Global Change. Academic Press, New York, USA.

SCHMIDT, S., 2007. Analyse der urbanen Vegetation innerhalb ausgewählter Stadtstrukturen von Recife, Pernambuco, Brasilien. Diplomarbeit. Universität Leipzig; Fakultät für Biowissenschaften, Psychologie und Pharmazie; 2007.

SCUDO G., 2002. Thermal Comfort in Greenspace. Proceeding COST C 11 "Green structures and urban planning" - Milan Oct 2002

SINO, 2005. International symposium on ecosystem carbon balance and cycle: Theory and application. Ecologists association overseas. Available from: www.sino-eco.org.

SKELLERN, C., 2011. Shadow display. Available from: http://www.chrisskellern.co.uk /arborshadow _site/shadow_display.htm

SPANGENBER, J.; SHINZATO, P.; JOHANSSON, E.; DUARTE, D., 2008. Simulation of the Influence of Vegetation on Microclimate and thermal Comfort in the City of Sao Paulo. Rev. SBAU, Piracicaba, v.3, n.2.

STANHILL, G., 1970. Some results of helicopter measurements of the albedoo for different land surfaces, Sol. Energy, 13, 59-66, 1970.

STEHFEST et al., 2009. Climate benefits of changing diet. Climatic Change, Earth and Environmental Science. Springer Neatherlands.

STERN REVIEW, 2008. International assessment of agricultural science and technology. Available from: http://maps.grida.no/go/graphic/go/ collection/iaastd-international-assessment-of-agricultural-science-andtechnology- for-development [Accessed on the 20 January 2009].

STOFFBERG, G. H.; VANROOYEN, M. W.; VANDERLINDE, M. J.; GROENEVELD, H. T., 2010. Carbon sequestration estimates of indigenous street trees in the City of Tshwane, SouthAfrica. Urban forestry and urban greening, Elsevier.

STREIFFELER, F., 1991. The knowledge system and the action motives in urban agriculture in subsaharan Africa. In: Proceedings of the International Workshop Agricultural Knowledge Systems and the Role of Extension, Bad Boll, p. 256-265. Institute of Socio-Economics of Agricultural Development, Faculty of International Agricultural Development, Technical University of Berlin, Podbielskiallee 64, D-1000 Berlin 33, Germany.

SUPPAN, P., 2010. Assessment of air pollution in the conurbation of Munich: present and future. International Journal of Environment and Pollution, 40:1,2,3(149-159).

TACOLI, C., 2003. The links between urban and rural development. Development planning unit; University college, London.

TAHA, H.; AKBARI, H.; ROSENFELD, A.; HUANG, J., 1988. Residential cooling loads and the urban heat island-the effects of albedo. Building and Environment, 23 (4), pp. 271-283.

TAN, P.Y., 2009. Understanding the Performance of Plants on non-irrigated Green Roofs in Singapore using a Biomass Yield Approach. National University of Singapore. Centre for Urban Greenery and Urban Ecology. Singapore.

TARNOCAI, C.; CANADELL, J.G.; SCHUUR, E.A.G.; KUHRY, P.; MAZHITOVA, G.; ZIMOV, S., 2009.
Soil organic carbon pools in the northern circumpolar permafrost region. Global Biogeochemical
Cycles 23, GB2023

THE AMSTERDAM DECLARATION ON GLOBAL CHANGE, 2001. Challenges of a Changing Earth: Global Change Open Science Conference Amsterdam. The Netherlands, 13 July 2001.

TIAN, H.; CHEN, G.; LIU, M.; ZHANG, C.; SUN, G.; LU, C.; XU, X.; REN, W.; PAN, S.; CHAPPELKA, A., 2010. Model estimates of net primary productivity, evaportranspiration, and water use efficiency in the terrestrial ecosystems of the southern United States. Forest Ecology and Management, Vol. 259: 1311-1327.

TIWARI, A.K., SINGH, J.S., 1987. Analysis of forest landuse and vegetation in a part of central Himalaya, using aerial photographs. Enviro Conserv. :14,233-244.

TOLLENAAR, T., 2008. Water Relations II: Stomatal Regulation and the Leaf Energy Balance. Lecture Notes for Thursday 13 November 2008. Crop Physiology, University of Guelph. http://www.uoguelph.ca/plant/courses/pbio-3110/

TÖPFER, T., 2007. Erholen, wohnen, arbeiten – Freiflächen in Städten des Südens: Bedeutungen, Nutzungen und Konflikte aus Sicht der Bewohner, Das Beispiel Apipucos (Recife, Brasilien). Geographisches Institut der Eberhard Karls Universität Tübingen.

TORRICO, JC.; JANSSENS, M. 2006. Agriculture as producer and consumer of energy case study of faring systems in RJ-Brazil. In: Book of Proceedings of RIO 6, "International RIO 6 - World Climate & Energy Event". pp 133-140.

TORRICO, JC.; JANSSENS, M. 2009. Biomass and Energy Assessment of Different Natural and Agricultural Systems in Brazil. Agriculturae Conspectus Scientificus. Vol. 74 No. 1 (1-6)

TRUMPER, K.; BERTZKY, M.; DICKSON, B.; VAN DER HEIJDEN, G.; JENKINS, M.; MANNING, P., 2009. The Natural Fix? The role of ecosystems in climate mitigation. A UNEP rapid response assessment. United Nations Environment Programme, UNEPWCMC, Cambridge, UK

TURNER, W.R.; OPPENHEIMER, M.; WILCOVE, D.S., 2009. A force to fight global warming. Nature 428(7271): 278–279. In: Bruno Locatelli, Vanessa Evans, Andrew Wardell, Angela Andrade, Raffaele Vignola, 2010. Forests and climate change in Latin America, Linking adaptation and mitigation in projects and policies. CIFOR, brief info, No. 31, November 2010. www.cifor.cgiar.org

UKIDWE, N.U. and BAKSHI, B.R., 2004. Thermodynamic Accounting of Ecosystem Contribution to Economic Sectors with Application to 1992 US Economy, Environmental Science and Technology 38 (18): 4810-4827.

UNDP, 1996. United Nations Development Programme, Human Development Report 1996. UNDP, New York. In: Nellemann, C., MacDevette, M., Manders, T., Eickhout, B., Svihus, B., Prins, A. G., Kaltenborn, B. P. (Eds). February 2009. The environmental food crisis – The environment's role in averting future food crises. A UNEP rapid response assessment. United Nations Environment Programme, GRID-Arendal, www.grida.no

UNEP, 2009. Yearbook, New science and developements in our changing environment; United nations environment programme.

UNEP, 2011. Towards a Green Economy. Pathways to sustainable and poverty eradication. Available from: www.unep.org/greeneconomy.

UNESCO, 2003. Water for People, Water for Life. The United Nations Development Report, France.

UN-HABITAT, 2006. The State of the World's Cities Report 2006/2007. London.

UN-HABITAT, 2009. Global Report on Human Settlements 2009, Planning Sustainable Cities: policy Directions. United Nations Human Settlements Programme. EARTHSCAN, USA.

UN-HABITAT, 2010. Climate Change Strategy 2010-2013. Available from: http://www.unhabitat.org /pmss/listItemDetails.aspx?publicationID=2861

VAUGHAN, N.E.; LENTON, T.M.; SHEPHERD, J.G., 2009. Climate change mitigation: tradeoffs between delay and strength of action required. Climatic Change, 1-15 (In Press).

WANG, M. and OVERLAND, J.E., 2009. A sea ice free summer Arctic within 30 years? Geophysical
Research Letters 36, L07502

WHITE, M.A.; NEMANI, R.R.; THORNTON, P.E.; RUNNING, S.W., 2002. Satellite evidence of phenological differences between urbanized and rural areas of the eastern United States deciduous broadleaf forest. Ecosystems, 5, 260-273.

WHITEFIELD, 2005. Permaculture in a Nutshell, 4th Edition. Permanent Publications Hyden House Limited, England.

WIEBEL, E., 2008. Peri-urban Development in Recife - An Empirical Study on the Social, Economic and Ecological Transformation Processes in the Peri-urban Space of Recife / Brazil. Institut für Geographie; Fachbereich Geowissenschaften. Universität Hamburg.

WILLIAMS, N.S.G., et al., 2010. Green roofs for a wide brownland: Opportunities and barriers for roof top greening in Australia. Urban Forestry and Urban Greening. Australia.

WINTERS, G., 2005. Landscape design project in the city of Vinhedo, Sao Paulo, Brazil from 1998 to 2005. Available from: http://www.centropaisagistico.com.br/mostra _projetos.asp

WONG, 2010. Reducing Urban Heat Islands: Compendium of Strategies. Environmental Protection Agency's Office of Atmospheric Programs. Climate Protection Partnership Division, USA.

WORLD BANK, 2000. World Bank Development Report 2000/2001. Oxford University press, New York.

YAMANO, H.K.; SUGIHARA; NOMURA, K., 2011. Rapid poleward range expansion of tropical reef corals in response to rising sea surface temperatures. Geophys. Res. Lett., 38, L04601, doi:10.1029/2010GL046474.

YU, G.; SONG, X.; WANG, Q.; LIU, Y.; GUAN, D.; YAN, J.; SUN, X.; ZHANG, L.; WEN, X., 2008. Water-use efficiency of forest ecosystems in eastern China and its relations to climatic variables. New Phytologist, 177: 927–937. doi: 10.1111/j.1469-8137.2007.02316.x

ZEEUF, H., 2005. Adequate services for sustainable urban agriculture. In: RUAF, 2005. Resource centre on urban agriculture and forestry; Book-Annotated bibliography on urban agriculture. Available from: www.ruaf.com

ZEEUW, H., 2004. The development of Urban Agriculture: some lessons learnt. Key note paper for the International Conference: Urban Agriculture, Agro-tourism and City Region Development, Beijing.

10 ANNEXES

Annex 1: Questionnaire applied to single households

Data:	Entrevistador:

A-Dados cadastrais (chefe de familia):					
No.:	Aspecto da paisagem:		Nome do Proprietario:	Contato:	Coordenadas:
	Rural				° ' ''
	Peri-urbana				
	Urbana				
No.Pessoas/res.:	Renda anual total.:		No.de filhos:		Situacao legal do Posse:
Profissao:	Onde trabalha:		Grau de escolaridade:		

B-Fisico natural:	
B.1-Vocacao geral	
Vocacao agricola da regiao:	Vocacao nao agricola da regiao:

B.2-Solo		
Tipo de solo predominante:	Fertilidade em geral:	
	Muito alta:	Regular:
	Alta:	Baixa:

B.3-Distribuicao do terreno:			
Area total:	A.pastagem:	A.flor.medio:	A.recre.pub.espo.:
A.construção:	A.ornam:	A.flor.avanç.:	A.Arbor. de ruas:
A.hortaliças:	A.perenes:	A.recre. part.:	A.baldia:
A.cult.anuais:	A.flor.Inicial:	A.recre. Pub.Plan.:	A.des.lixo:

B.6 - Topograia (plano, suave/medio/forte ondulado):	**B.7 - Isolamento fisico (ilha, estrada, relevo, ...)**

B.8 - Grau de Risco (1 = inexistente; 2 = baixo; 3 = medio; 4 = alto)		
Erosao:	Enchente:	Seguranca:

B.9 - Uso da agua:		
	Procedencia:	**Intensid. (baixa,media,alta):**
Consumo domestico:		
Irrigacao:		
Animais:		

C-Dados historicos do uso da terra:	
Quando veio morar aqui?	Como era a regiao antes?
Quais foram as principais mudancas?	Onde morava antes? (cidade/campo):
Havia florestas? Havia exploracao?	Havia agricultura? O que era produzido?
Como era o aspecto do seu terreno?	Como adquiriu? (comprou, invadiu, heranca…)

D-Motivacoes:	
D.1-Percepcao:	
A vida melhorou ou piorou desde que veio? Por que?	Pensa que a familia vai aumentar? Tera mais moradores?
Pensa em sair daqui? Por que?	Pensa em aumentar a construcao? Por que?
Pensa em vender parte do terreno? Por que?	Pensa em vender a propriedade? Por que?
Pensa em plantar algo? O que? Por que?	Onde gostaria de morar se nao aqui? Por que?
Tem problemas de saude na familia? Quais?	Gosta da vizinhanca? Por que?
Ja ofereceram algo pela sua propiedade? Que tipo de proposta (dinheiro, troca,servico, dividas…)	
Ja teve problemas com IBAMA, DEPRN & Co.? Por que? Como foi resolvido?	

D.2-Tomada de decisao:				
Quais os principais motivos para ter vindo morar (trabalhar) aqui (marcar com "x"):				
Condicoes para producao	Contato c/ natureza	Preco bom da terra	Proxim. da cidade	Proxim. do trabalho
Falta de opcao	Heranca	Invasao ou apropriacao	Seguranca	Religiao
Quais os principais motivos para continuar a morar (trabalhar) aqui (marcar com "x"):				
Condicoes para producao	Contato c/ natureza	Preco bom da terra	Proxim. da cidade	Proxim. do trabalho
Falta de opcao	Heranca	Legaliza/regularizacao	Seguranca	Religiao

E-Dados socio-economicos:			
E.1-Importancia social:			
No.empr.fixos formais:	No.empr.fixos informais:	No.empr.temp.formais	No.empr.temp.informais
E.2-Patrimonio:			
Valor da terra (R$/m² -ha):	Valor total das bemfeitorias:	Valor total das Maquinas:	Investimento total:
E.3-Producao:			
	Canal de escoacao:	**Ingresso mensal ou anual: (R$)**	**Observacoes:**
Hortalica			
Cult.			
Pastage			
Cult.			
Cult.			
Prod.			
Recreaca			
Observacoes:			

Annex 2: List of Species in the experimental systems, their use and origin (adapted from Schmidt 2007)

		U S E				Experimental System					
Family	**Species**	**O**	**N**	**A**	**Origin**	**Fallow land**	**Rec. areas**	**Annual crops**	**Perennial crops**	**Street trees**	**Nat. forest**
Acanthaceae	*Barleria repens Nees*	x			AFR		x				
Acanthaceae	*Hemigraphis colorata (Blume) Hallier f.*	x			NAM		x				
Acanthaceae	*Justicia brandegeana Wassh. & L.B. Sm.*	x			NAM		x				
Acanthaceae	*Justicia schomburgkiana (Nees) V.A.W. Graham*	x			SAM	x					
Acanthaceae	*Pseuderanthemum atropurpureum (W. Bull)*	x			AUS	x					
Acanthaceae	*Ruellia paniculata L.*				?	x					
Acanthaceae	*Sanchezia nobilis Hook.*	x			SAM		x				
Acanthaceae	*Thunbergia Retz.*				PÄT		x				
Aizoaceae	*Tetragonia tetragonioides*				NZ			x			
Alliaceae	*Allium fistulosum*				CH			x			
Amaranthaceae	*Celosia cristata L.*	x			NT		x				
Amaryllidaceae	*Agave americana L.*	x			MAM		x				
Amaryllidaceae	*Crinum erubescens Aiton*	x			NT						
Amaryllidaceae	*Hymenocallis Salisb.*	x			NT		x				
Anacardiaceae	*Anacardium occidentale L.*		x	x	BRA		x				
Anacardiaceae	*Mangifera indica L.*		x	x	SA	x	x		x		
Anacardiaceae	*Schinus terebinthifolius Raddi*			x	SAM	x					
Anacardiaceae	*Spondias lutea L.*		x		SAM		x				
Anacardiaceae	*Thyrsodium schomburgkianum Benth.*				AMZ				x		
Annonaceae	*Annona muricata L.*		x		NT		x				
Annonaceae	*Annona muricata L.*		x		NT						
Annonaceae	*Annona squamosa L.*		x		NT						
Annonaceae	*Xylopia frutescens Aubl.*				SAM	x	x		x	x	
Annonaceae	*Xylopia frutescens Aubl.*				SAM	x				x	
Apiaceae	*Hydrocotyle umbellata L.*				PT?						
Apocynaceae	*Allamanda cathartica L.*	x			SAM		x				
Apocynaceae	*Catharanthus roseus var. albus G. Don*	x			PT	x	x				
Apocynaceae	*Ervatamia coronaria (Jacq.) Stapf*	x			BRA		x				
Apocynaceae	*Mandevilla scabra*				NT	x					
Apocynaceae	*Mandevilla scabra var. glabrata*				NT	x					
Apocynaceae	*Nerium oleander L.*	x			MED	x	x				
Apocynaceae	*Plumeria acutifolia Poir.*	x			MAM						
Apocynaceae	*Tabernaemontana laeta Mart.*	x			OA	x					
Apocynaceae	*Thevetia peruviana (Pers.) K. Schum.*	x			NT		x				
Araceae	*Aglaonema commutatum var. maculatum*	x			SOA						
Araceae	*Alocasia macrorrhizos (L.) G. Don*	x	x		SOA	x					
Araceae	*Anthurium andraeanum Hybride Linden*	x			SAM	x					
Araceae	*Caladium bicolor (Aiton) Vent.*				ZA	x			x		
Araceae	*cf. Arisaema Mart.*				?	x					
Araceae	*Dieffenbachia amoena Bull.*	x			NT	x			x		
Araceae	*Epipremnum pinnatum (L.) Engl.*	x			AUS	x					
Araceae	*Epipremnum pinnatum (L.) Engl.*	x			AUS	x	x		x		
Araceae	*Monstera deliciosa Liebm.*	x			NAM						

Araceae	*Philodendron aff. melinonii Brongn. ex Regel*	x			SAM						
Araceae	*Philodendron bipinnatifidum Schott ex Endl.*	x			NT	x					
Araceae	*Philodendron imbe Schott*	x			NT	x					
Araceae	*Philodendron imbe Schott*	x			NT	x			x		
Araceae	*Philodendron quinquelobum K. Krause*				AMZ				x		
Araceae	*Philodendron Schott*				NT						
Araceae	*Syngonium podophyllum Schott*	x			NT						
Araceae	*Syngonium vellozianum Schott*	x			SAM						
Araliaceae	*Polyscias filicifolia (C. Moore ex E. Fourn.)*	x			AUS		x				
Araliaceae	*Polyscias guilfoylei (W. Bull) L.H. Bailey*	x			AUS						
Araliaceae	*Schefflera arboricola Hayata*	x			AFR						
Araliaceae	*Schefflera morototoni (Aubl.) Maguire, Steyerm.*				BRA?	x			x		
Araucariaceae	*Araucaria Juss.*	x			SAM		x				
Arecaceae	*Acrocomia intumescens Drude*				BRA	x	x				
Arecaceae	*Bactris acanthocarpa var. acanthocarpa Mart.*	x			SAM						
Arecaceae	*Barcella odora (Trail) Drude*				SAM				x		
Arecaceae	*Caryota mitis Lour.*	x			SOA				x		
Arecaceae	*Cocos nucifera L.*	x	x		SOA	x	x				
Arecaceae	*Copernicia prunifera (Mill.) H.E. Moore*	x			BRA		x				
Arecaceae	*Dypsis lutescens (H. Wendl.) Beentje & J.*	x			MAD		x				
Arecaceae	*Elaeis oleifera (Kunth) Cortés*		x		AFR						x
Arecaceae	*Elaeis oleifera (Kunth) Cortés*		x		AFR						x
Arecaceae	*Euterpe oleracea Mart.*	x			SAM		x				
Arecaceae	*Geonoma Willd.*				SAM						x
Arecaceae	*Geonoma Willd.*				SAM						x
Arecaceae	*Licuala grandis H. Wendl. ex Linden*	x			PÄT		x				
Arecaceae	*Pinanga merrillii Hort.*	x			SOA		x				
Arecaceae	*Pinanga Sp.1 Blume*	x			SOA		x				
Arecaceae	*Pinanga Sp.2 Blume*	x			SOA		x				
Arecaceae	*Pritchardia pacifica Seem. & H. Wendl.*	x			AUS		x				
Arecaceae	*Pritchardia sp.*	x			AUS		x				
Arecaceae	*Ptychosperma Labill.*	x			AUS		x				
Arecaceae	*Ptychosperma macarthurii*	x			AUS		x				
Arecaceae	*Rhapis excelsa (Thunb.) A. Henry ex Rehder*	x			ZA		x				
Arecaceae	*Roystonea cf. oleracea (Jacq.) O.F. Cook*	x			MAM					x	
Arecaceae	*Roystonea oleracea (Jacq.) O.F. Cook*	x			MAM		x				
Arecaceae	*Sabal Adans.*	x			NAM		x				
Asclepiadaceae	*Asclepias curassavica L.*				PT						
Asclepiadaceae	*Blepharodon nitidum (Vell.) J.F. Macbr.*				SAM	x					
Asclepiadaceae	*Calotropis gigantea (L.) R. Br.*			x	AS						
Asclepiadaceae	*Matelea cf. maritima (Jacq.) Woodson*				BRA?						
Asteraceae	*Ageratum conyzoides L.*				PT	x					
Asteraceae	*cf. Gorceixia Baker*				?	x					
Asteraceae	*Cichorium endivia*				EUR			x			
Asteraceae	*Cichorium intybus*				EUR			x			
Asteraceae	*Lactuca sativa*				EUR			x			
Asteraceae	*Verbesina macrophylla (Cass.) S.F. Blake*				?	x					
Asteraceae	*Vernonia brasiliensis (Spreng.) Less.*				SAM	x					
Balsaminaceae	*Impatiens walleriana Hook. f.*	x			AFR		x				
Bignoniaceae	*Adenocalymma bracteatum (Cham.) DC.*				BRA	x					
Bignoniaceae	*cf. Cydista Miers*	x			?		x				
Bignoniaceae	*Crescentia cujete L.*	x	x		NT		x				
Bignoniaceae	*Lundia cordata (Vell.) A. DC.*				SAM	x					

Bignoniaceae	*Tabebuia cf. heptaphylla (Vell.) Toledo*			x	BRA						x
Bignoniaceae	*Tabebuia cf. heptaphylla (Vell.) Toledo*			x	BRA						x
Bignoniaceae	*Tabebuia impetiginosa (Mart. ex DC.) Standl.*			x	BRA						x
Bignoniaceae	*Tecoma stans (L.) Juss. ex Kunth*	x			MAM		x				
Bombacaceae	*Eriotheca cf. crenulaticalyx A. Robyns*				SAM						x
Bombacaceae	*Eriotheca cf. crenulaticalyx A. Robyns*				SAM						x
Bombacaceae	*Pachira aquatica Aubl.*			x	BRA?		x				
Boraginaceae	*Cordia polycephala (Lam.) I.M. Johnst.*				NT	x	x				
Boraginaceae	*Heliotropium angiospermum Murray*				NT	x					
Boraginaceae	*Heliotropium elongatum Hoffm. ex Roem.*				SAM	x					
Boraginaceae	*Tournefortia rubicunda Salzm. ex DC.*				?	x					
Brassicaceae	*Barbarea verna*				EUR			x			
Brassicaceae	*Brassica oleracea*				MED			x			
Brassicaceae	*Brassica oleracea*				MED			x			
Brassicaceae	*Brassica pekinensis*				CH			x			
Brassicaceae	*Brassica rapa*				EUR			x			
Brassicaceae	*Eruca sativa*				MED			x			
Brassicaceae	*Raphanus sativus*				MED			x			
Bromeliaceae	*Aechmea farinosa (Regel) L.B. Sm.*	x			NT						
Bromeliaceae	*Ananas bracteatus (Lindl.) Schult. & Schult. f.*	x			SAM		x				
Bromeliaceae	*Ananas comosus (L.) Merr.*		x		SAM		x				
Burseraceae	*Protium heptaphyllum (Aubl.) Marchand*				BRA				x		
Burseraceae	*Protium heptaphyllum (Aubl.) Marchand*				BRA				x		
Cactaceae	*Rhipsalis baccifera (J.S. Muell.) Stearn*	x			PT		x				
Cannaceae	*Canna denudata Roscoe*	x			NT		x				
Cannaceae	*Canna x generalis L.H. Bailey*	x			NT		x				
Capparaceae	*Cleome spinosa Jacq.*			x	C	x	x				
Capparaceae	*Crateva tapia L.*				NT	x					
Caricaceae	*Carica papaya L.*		x		MAM		x				
Cecropiaceae	*Cecropia Loefl.*				PT	x					
Chenopodiaceae	*Beta vulgaris var. cicla*				EUR			x			
Chrysobalanaceae	*Couepia rufa Ducke*				BRA				x		
Chrysobalanaceae	*Hirtella L.*				?				x		
Chrysobalanaceae	*Licania cf. tomentosa (Benth.) Fritsch*				SAM						
Chrysobalanaceae	*Licania tomentosa (Benth.) Fritsch*				SAM	x	x		x		
Chrysobalanaceae	*Licania tomentosa (Benth.) Fritsch*				SAM				x		
Chrysobalanaceae	*Licania tomentosa (Benth.) Fritsch*				SAM				x		
Clusiaceae	*Clusia fluminensis Planch. & Triana*				NT		x				
Clusiaceae	*Vismia guianensis (Aubl.) Pers.*				SAM	x					
Combretaceae	*Laguncularia racemosa (L.) C.F. Gaertn.*				SAM						
Combretaceae	*Terminalia catappa L.*			x	VA		x				
Combretaceae	*Terminalia cf. catappa L.*			x	VA	x					
Commelinaceae	*Tradescantia pallida var. purpurea (Rose) D.R.*	x			MAM	x					
Commelinaceae	*Tradescantia spathacea Sw.*	x			NAM	x	x				x
Commelinaceae	*Tradescantia zebrina Heynh.*	x			NAM		x				x
Convolvulaceae	*Calonyction bona-nox (L.) Bojer*	x			NT						
Convolvulaceae	*Ipomoea asarifolia (Desr.) Roem. & Schult.*				PT	x					
Convolvulaceae	*Ipomoea batatas (L.) Lam.*		x		SAM				x		
Convolvulaceae	*Merremia umbellata (L.) Hallier f.*				PT	x					
Cucurbitaceae	*Cucumis sativus*				IND			x			
Cucurbitaceae	*Cucurbita cf. maxima Duchesne*		x		NT				x		
Cucurbitaceae	*Momordica charantia L.*				SA	x	x				
Cupressaceae	*Cupressus L.*	x			NH		x				

Cycadaceae	*Cycas circinalis L.*	x			PÄT		x				
Cyperaceae	*Cyperus alternifolius L.*	x			PT?		x				
Cyperaceae	*Cyperus laxus Lam.*				NT	x					
Cyperaceae	*Cyperus ligularis L.*				PT?	x					
Cyperaceae	*Cyperus odoratus L.*				PT?				x		
Cyperaceae	*Rhynchospora cephalotes (L.) Vahl*				BRA	x					
Cyperaceae	*Scleria cf. pterota C. Presl*				C	x					
Dilleniaceae	*Davilla rugosa Poir.*				NT	x					
Elaeocarpaceae	*Muntingia calabura L.*	x		x	NT	x					
Elaeocarpaceae	*Sloanea cf. laxiflora Spruce ex Benth.*				AMZ						x
Erythroxylaceae	*Erythroxylum citrifolium A. St.-Hil.*				NT	x					x
Erythroxylaceae	*Erythroxylum citrifolium A. St.-Hil.*				NT	x					x
Euphorbiaceae	*Chamaesyce hirta (L.) Millsp.*				BRA?		x		x		
Euphorbiaceae	*Chamaesyce thymifolia (L.) Millsp.*				BRA?				x		
Euphorbiaceae	*Cnidoscolus urens (L.) Arthur*				NT	x					
Euphorbiaceae	*Codiaeum variegatum (L.) A. Juss.*	x			PT		x				
Euphorbiaceae	*Croton lobatus L.*				?	x					
Euphorbiaceae	*Croton triqueter Lam.*				SAM	x					
Euphorbiaceae	*Dalechampia L.*				PT	x					
Euphorbiaceae	*Euphorbia milii Des Moul.*	x			MAD		x				
Euphorbiaceae	*Jatropha curcas L.*	x		x	NT		x				
Euphorbiaceae	*Phyllanthus cf. tenellus Roxb.*			x	?		x				
Euphorbiaceae	*Ricinus communis L.*			x	AFR	x					
Euphorbiaceae	*Sebastiania corniculata (Vahl) Müll. Arg.*				?	x					
Euphorbiaceae	*Manihot esculenta Crantz*				BRA			x			
Fagaceae	*Castanea Mill.*		x		SEU						x
Flacourtiaceae	*Casearia cf. javitensis Kunth*				SAM	x					
Flacourtiaceae	*Casearia javitensis Kunth*				SAM						x
Flacourtiaceae	*Casearia javitensis Kunth*				SAM						x
Gesneriaceae	*Nautilocalyx forgetii (Sprague) Sprague*	x			AMZ		x				
Heliconiaceae	*Heliconia bihai "Lobster claw" (L.) L.*	x			NT		x				
Heliconiaceae	*Heliconia psittacorum L. f.*	x			NT	x					
Heliconiaceae	*Heliconia psittacorum L. f. x Heliconia*	x			NT	x					
Heliconiaceae	*Heliconia rostrata Ruiz & Pav.*	x			AMZ						
Iridaceae	*Trimezia fosteriana Steyerm.*	x			NT						
Lamiaceae	*Gattung 1*			x	?						
Lamiaceae	*Ocimum basilicum L.*			x	SA						
Lamiaceae	*Ocimum gratissimum L.*			x	SEU		x				
Lamiaceae	*Plectranthus cf. scutellarioides (L.) R. Br.*	x			MAM						
Lamiaceae	*Tetradenia riparia (Hochst.) Codd*	x		x	SAF						
Lauraceae	*Cinnamomum zeylanicum Blume*	x	x		SA	x					
Lauraceae	*Persea americana Mill.*		x		MAM						
Lecythidaceae	*Eschweilera cf. ovata (Cambess.) Miers*				BRA		x				
Lecythidaceae	*Eschweilera cf. ovata (Cambess.) Miers*				BRA		x				
Lecythidaceae	*Eschweilera ovata (Cambess.) Miers*				BRA	x					
Lecythidaceae	*Eschweilera ovata (Cambess.) Miers*				BRA						
Lecythidaceae	*Lecythis pisonis Cambess.*			x	SAM						
Lecythidaceae	*Lecythis pisonis Cambess.*			x	SAM						
Leguminosae, C	*Caesalpinia cf. pulcherrima (L.) Sw.*	x			ZA						
Leguminosae, C	*Caesalpinia echinata Lam.*			x	BRA		x				
Leguminosae, C	*Caesalpinia pulcherrima (L.) Sw.*	x			ZA		x				
Leguminosae, C	*Cassia fistula L.*	x			SA	x	x				
Leguminosae, C	*Cassia javanica L.*	x			SOA		x				

Leguminosae, C	*Delonix regia (Bojer ex Hook.) Raf.*	x			MAD	x					
Leguminosae, C	*Dialium guianense (Aubl.) Sandwith*				NT						
Leguminosae, C	*Dialium guianense (Aubl.) Sandwith*				NT						
Leguminosae, C	*Peltogyne aff. pubescens Benth.*				AMZ						
Leguminosae, C	*Senna alata (L.) Roxb.*	x			BRA?	x					
Leguminosae, C	*Senna georgica H.S. Irwin & Barneby*				NT		x				
Leguminosae, C	*Senna Mill.*				PT		x				
Leguminosae, C	*Senna siamea (Lam.) H.S. Irwin & Barneby*	x			SOA	x					
Leguminosae, C	*Tamarindus indica L.*		x		TAFR	x					x
Leguminosae, F	*Arachis repens Handro*	x			SAM		x				
Leguminosae, F	*Canavalia brasiliensis Mart. ex Benth.*				NT	x					
Leguminosae, F	*Canavalia ensiformis (L.) DC.*			x	AFR				x		
Leguminosae, F	*Centrosema brasilianum (L.) Benth.*				NT	x					
Leguminosae, F	*Clitoria fairchildiana R.A. Howard*	x		x	BRA	x	x				
Leguminosae, F	*Crotalaria pallida Aiton*				AFR						
Leguminosae, F	*Crotalaria retusa L.*				AS	x					
Leguminosae, F	*Dalbergia ecastaphyllum (L.) Taub.*				PT	x					
Leguminosae, F	*Erythrina variegata L.*	x		x	SOA					x	
Leguminosae, F	*Macroptilium cf. martii (Benth.)*				NT	x					
Leguminosae, F	*Macroptilium lathyroides (L.) Urb.*				NT	x					
Leguminosae, F	*Sesbania marginata Benth.*				SAM	x					
Leguminosae, F	*Stylosanthes scabra Vogel*				SAM	x					
Leguminosae, F	*Swartzia pickelii Killip ex Ducke*				NT						x
Leguminosae, F	*Tephrosia cinerea (L.) Pers.*				PT						
Leguminosae, F	*Tipuana tipu (Benth.) Kuntze*			x	SAM		x				
Leguminosae, M	*Acacia cf. auriculiformis A. Cunn. ex Benth.*	x			AUS						x
Leguminosae, M	*Adenanthera pavonina L.*	x			SOA		x				
Leguminosae, M	*Calliandra inaequilatera Rusby*				NT?		x			x	
Leguminosae, M	*Calliandra spinosa Ducke*	x			NT?		x				
Leguminosae, M	*Inga capitata Desv.*				NT						x
Leguminosae, M	*Inga sp.1 Mill.*				NT						x
Leguminosae, M	*Inga sp.2 Mill.*				NT		x				
Leguminosae, M	*Leucaena leucocephala (Lam.) de Wit*				PT	x					
Leguminosae, M	*Mimosa bimucronata (DC.) Kuntze*				NT?						
Leguminosae, M	*Mimosa caesalpiniifolia Benth.*				NT?	x					
Leguminosae, M	*Parkia pendula (Willd.) Benth. ex Walp.*	x			NT						x
Leguminosae, M	*Parkia platycephala Benth.*				BRA						x
Leguminosae, M	*Piptadenia cf. gonoacantha (Mart.) J.F. Macbr.*				SAM						x
Leguminosae, M	*Pithecellobium dulce (Roxb.) Benth.*	x			NAM	x					
Leguminosae, M	*Plathymenia foliolosa Benth.*				BRA						x
Leguminosae, M	*Plathymenia foliolosa Benth.*				BRA						x
Liliaceae	*Asparagus setaceus (Kunth) Jessop*	x			SAF		x				
Liliaceae	*Chlorophytum comosum (Thunb.) Jacques*	x			SAF		x				
Liliaceae	*Cordyline terminalis (L.) Kunth*	x			SOA		x				
Liliaceae	*Dracaena fragrans (L.) Ker Gawl.*				AFR		x				x
Liliaceae	*Dracaena marginata hort.*	x			MAD		x				
Liliaceae	*Dracaena sanderiana hort.*	x			AFR		x				
Liliaceae	*Sansevieria cylindrica Bojer*	x			TAFR		x			x	
Liliaceae	*Sansevieria trifasciata Prain*	x		x	TAFR		x				x
Loranthaceae	*cf. Struthanthus Mart.*				NT		x				
Loranthaceae	*Phthirusa pyrifolia (Kunth) Eichler*				NT		x				
Lythraceae	*Cuphea gracilis Kunth*	x			BRA?		x				
Malpighiaceae	*Galphimia brasiliensis (L.) A. Juss.*	x			NT		x				

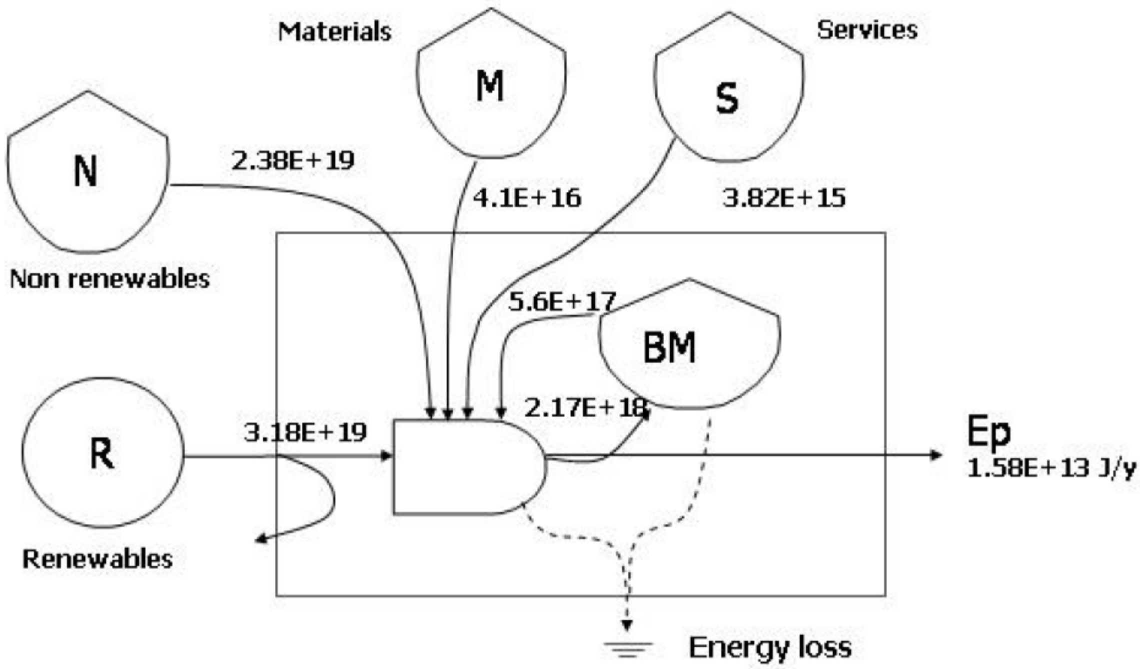
Malpighiaceae	*Malpighia glabra L.*		x		MAM		x				
Malvaceae	*Abelmoschus esculentus (L.) Moench*		x		SOA				x		
Malvaceae	*Hibiscus rosa-sinensis L.*	x			ZA		x				
Marantaceae	*Calathea cf. brasiliensis Körn.*	x			NT						x
Marantaceae	*Ctenanthe setosa Eichler*	x			SAM		x				
Melastomataceae	*Clidemia D. Don*				NT	x					
Melastomataceae	*Miconia albicans (Sw.) Triana*				NT	x					
Melastomataceae	*Miconia albicans (Sw.) Triana*				NT	x					x
Melastomataceae	*Miconia cuspidata Mart. ex Naudin*				SAM						
Melastomataceae	*Miconia minutiflora (Bonpl.) DC.*				NT						x
Melastomataceae	*Miconia minutiflora (Bonpl.) DC.*				NT	x					
Melastomataceae	*Miconia prasina (Sw.) DC.*				NT	x					x
Meliaceae	*Azadirachta indica A. Juss.*	x		x	VA		x				
Meliaceae	*Carapa cf. guianensis Aubl.*			x	SAM	x					x
Meliaceae	*Carapa guianensis Aubl.*			x	SAM	x					x
Meliaceae	*Gattung 1*				?						x
Moraceae	*Artocarpus communis J.R. Forst. & G. Forst.*		x	x	SOA		x				
Moraceae	*Artocarpus heterophyllus Lam.*		x	x	SA		x		x		x
Moraceae	*Ficus elastica Roxb.*	x			SOA		x				
Moraceae	*Ficus pumila L.*	x			PÄT		x				
Moraceae	*Sorocea A. St.-Hil.*				SAM						x
Musaceae	*Musa x paradisiaca L.*		x		SOA	x	x		x		
Myrtaceae	*Callistemon salignus (Sm.) Sweet*	x			AUS		x				
Myrtaceae	*Eucalyptus citriodora Hook.*			x	AUS	x					x
Myrtaceae	*Eugenia uniflora L.*		x		BRA?	x	x				x
Myrtaceae	*Gattung 1*				?						x
Myrtaceae	*Gattung 2*				?	x					
Myrtaceae	*Gattung 3*				?						x
Myrtaceae	*Myrcia sylvatica (G. Mey.) DC.*				SAM	x					
Myrtaceae	*Myrciaria aff. floribunda (H. West ex Willd.) O.*				SAM	x					
Myrtaceae	*Myrciaria cauliflora (Mart.) O. Berg*				BRA						
Myrtaceae	*Psidium guajava L.*		x		MAM	x	x				
Myrtaceae	*Syzygium aqueum (Burm. f.) Alston*		x		SOA						
Myrtaceae	*Syzygium cf. cumini (L.) Skeels*		x	x	SA	x					
Myrtaceae	*Syzygium cumini (L.) Skeels*		x	x	SOA	x					
Myrtaceae	*Syzygium malaccense (L.) Merr. & L.M. Perry*		x		SOA						
Myrtaceae	*Syzygium samarangense (Blume) Merr. & L.M.*		x	x	SOA	x	x				
Nephrolepidaceae	*Nephrolepis cf. exaltata (L.) Schott*	x			NT						
Nephrolepidaceae	*Nephrolepis sp.1 Schott*				PT?		x				
Nephrolepidaceae	*Nephrolepis sp.3 Schott*	x			PT?						
Nyctaginaceae	*Bougainvillea spectabilis Willd.*	x			SAM						
Onagraceae	*Ludwigia cf. leptocarpa (Nutt.) H. Hara*				?	x					
Orchidaceae	*Arundina bambusifolia Lindl.*	x			SOA						
Orchidaceae	*Gattung 1*	x			?	x					
Orchidaceae	*Gattung 2*	x			?						
Orchidaceae	*Oeceoclades maculata (Lindl.) Lindl.*				?	x	x				
Oxalidaceae	*Averrhoa carambola L.*		x		SOA						
Pandanaceae	*Pandanus Parkinson*	x			SOA		x				
Passifloraceae	*Passiflora quadrangularis L.*				MAM	x					
Phytolaccaceae	*Petiveria foetida Salisb.*			x	MAM	x					
Piperaceae	*Peperomia pellucida (L.) Kunth*			x	?	x					
Piperaceae	*Piper cf. tuberculatum Jacq.*				PT?						
Piperaceae	*Piper marginatum Jacq.*				PT?	x	x				

Piperaceae	*Piper tuberculatum Jacq.*				PT?	x					
Poaceae	*Bambusa Schreb.*	x		x	SOA						
Poaceae	*Cymbopogon citratus (DC.) Stapf*			x	SA	x					
Poaceae	*Echinochloa polystachya (Kunth) Hitchc*				?		x				
Poaceae	*Ichnanthus P. Beauv.*				NT	x					
Poaceae	*Lasiacis divaricata (L.) Hitchc.*				NT	x					
Poaceae	*Panicum dichotomiflorum Michx.*				?	x					
Poaceae	*Paspalum millegrana Schrad.*				NT	x					
Poaceae	*Pennisetum purpureum Schumach.*			x	AFR	x					
Poaceae	*Saccharum officinarum L.*		x		SOA	x	x				
Poaceae	*Sorghum halepense (L.) Pers.*				AFR	x					
Poaceae	*Sporobolus indicus (L.) R. Br.*				?	x					
Poaceae	*Streptostachys asperifolia Desv.*				SAM	x					
Poaceae	*Urochloa arrecta*				PÄT	x					
Poaceae	*Urochloa maxima (Jacq.) R.D. Webster*				PÄT	x					
Poaceae	*Urochloa mutica (Forssk.) T.Q. Nguyen*				PÄT						
Poaceae	*Zea mays L.*		x		MAM				x		
Podocarpaceae	*Podocarpus macrophyllus (Thunb.) Sweet*	x			OA		x				
Polygonaceae	*Polygonum acuminatum Kunth*	x			BRA						
Polypodiaceae	*Phymatodes scolopendria (Burm. f.) Ching*	x			SA		x				
Polypodiaceae	*Platycerium bifurcatum (Cav.) C. Chr.*	x			AUS		x				
Pontederiaceae	*Eichhornia crassipes (Mart.) Solms*			x	NT						
Portulacaceae	*Portulaca grandiflora Hook.*	x			BRA		x				
Portulacaceae	*Talinum paniculatum (Jacq.) Gaertn.*			x	NT				x		
Pteridaceae	*Pteris vittata L.*				PT						x
Punicaceae	*Punica granatum L.*		x		MED		x				
Rhamnaceae	*Ziziphus joazeiro Mart.*		x	x	NT						
Rosaceae	*cf. Cotoneaster*				ZA		x				
Rosaceae	*Rosa chinensis Jacq.*	x			ZA		x				
Rosaceae	*Rosa x grandiflora Hort.*	x			OA?		x				
Rubiaceae	*Borreria verticillata (L.) G. Mey.*				?						
Rubiaceae	*Genipa americana L.*		x		NT						x
Rubiaceae	*Ixora chinensis Lam.*	x			SOA		x				
Rubiaceae	*Ixora coccinea "Compacta" L.*	x			SOA		x				
Rubiaceae	*Ixora coccinea L.*	x			SOA		x				
Rubiaceae	*Ixora macrothyrsa Teijsm. & Binn.*	x			SOA		x				
Rubiaceae	*Mussaenda alicia Schumach. & Thonn.*	x			TAFR		x				
Rubiaceae	*Mussaenda incana Wall.*	x			ZA		x				
Rubiaceae	*Richardia grandiflora (Cham. & Schltdl.) Steud.*				?						
Rutaceae	*Citrus L.*		x		ZA		x				
Rutaceae	*Citrus L.*		x		ZA		x				
Rutaceae	*Citrus tangerina Tanaka*		x		ZA		x				
Rutaceae	*Murraya paniculata (L.) Jack*	x		x	SA		x				
Rutaceae	*Zanthoxylum cf. petiolare A. St.-Hil. & Tul.*				PT						x
Sapindaceae	*Cupania cf. racemosa (Vell.) Radlk.*				BRA	x					
Sapindaceae	*Cupania L.*				NT						x
Sapindaceae	*Cupania racemosa (Vell.) Radlk.*				BRA	x					
Sapindaceae	*Paullinia L.*				SAM	x					
Sapindaceae	*Paullinia pinnata L.*				SAM						x
Sapindaceae	*Talisia esculenta (A. St.-Hil.) Radlk.*		x		AMZ		x				
Sapotaceae	*Manilkara zapota (L.) P. Royen*		x		MAM						x
Sapotaceae	*Manilkara zapota (L.) P. Royen*		x		MAM						x
Saxifragaceae	*Hydrangea macrophylla (Thunb.) Ser.*	x			OA		x				

Schizaeaceae	*Lygodium venustum Sw.*				PT	x					
Scrophulariaceae	*Angelonia Humb. & Bonpl.*				BRA?				x		
Scrophulariaceae	*Scoparia dulcis L.*				?	x					
Scrophulariaceae	*Torenia fournieri Linden ex E. Fourn.*	x			NT		x				
Smilacaceae	*Smilax sp.1 L.*				?						x
Smilacaceae	*Smilax sp.2 L.*				?	x					
Solanaceae	*Capsicum annuum*				MAM			x			
Solanaceae	*Cestrum laevigatum Schltdl.*				NT	x					
Solanaceae	*Gattung 1*	x			?		x				
Solanaceae	*Physalis alkekengi L.*				ZA?				x		
Solanaceae	*Physalis neesiana Sendtn.*				SAM						
Solanaceae	*Solanum asperum Rich.*				SAM						
Solanaceae	*Solanum cf. americanum Mill.*			x	PT		x				
Solanaceae	*Solanum paniculatum L.*				SAM	x					
Strelitziaceae	*Ravenala madagascariensis Sonn.*	x			MAD		x				
Thelypteridaceae	*Thelypteris cf. dentata (Forssk.) E.P. St. John*				PT						
Turneraceae	*Turnera L.*				?		x				
Ulmaceae	*Trema micrantha (L.) Blume*				SAM	x					
Umbelliferae	*Apium graveolens*				EUR			x			
Umbelliferae	*Coriandrum sativum*				EUR			x			
Umbelliferae	*Daucus carota*				AFG			x			
Umbelliferae	*Petroselinum crispum*				MED			x			
Urticaceae	*Pilea microphylla (L.) Liebm.*				NT	x					
Verbenaceae	*Aegiphila vitelliniflora Klotzsch ex Walp.*				BRA	x					
Verbenaceae	*Citharexylum cf. ulei Moldenke*				NT	x					
Verbenaceae	*Clerodendrum x speciosum Teijsm. & Binn.*	x			TAFR		x				
Verbenaceae	*Duranta repens L.*	x			NT?		x				
Verbenaceae	*Gattung 1*				?						x
Verbenaceae	*Holmskioldia sanguinea Retz.*	x			ZA		x				
Verbenaceae	*Lantana camara L.*				NT	x					
Verbenaceae	*Lantana sp.1*				PT		x				
Verbenaceae	*Stachytarpheta elatior Schrad. ex Schult.*				SAM				x		
Verbenaceae	*Vitex agnus-castus L.*			x	MED		x				
Vitaceae	*Cissus verticillata (L.) Nicolson & C.E. Jarvis*				PT	x	x				
Vitaceae	*Leea coccinea Bojer*	x			SOA		x				
Vitaceae	*Leea rubra Blume ex Spreng.*	x			SOA		x				
Zingiberaceae	*Alpinia purpurata (Vieill.) K. Schum.*	x			AUS		x				
Zingiberaceae	*Alpinia speciosa (Blume) D. Dietr.*			x	OA		x				
Zingiberaceae	*Costus cf. arabicus L.*				NT						x
Zingiberaceae	*Costus cf. spiralis (Jacq.) Roscoe*				SAM		x				
Zingiberaceae	*Costus cuspidatus (Nees & Mart.) Maas*				BRA		x				

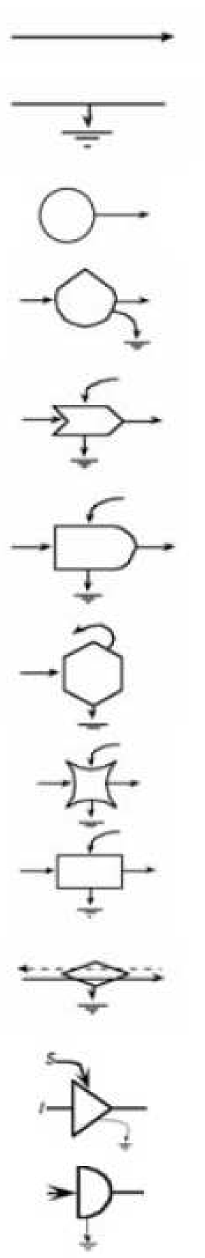
Annex 3: Emergy analysis: "Corrego Sujo Basin" in Teresopolis, Brazil (Torrico 2006)

Name of flow	Quantity (E+17 sej)
Local renewable sources (R)	318
Local non-renewable sources (N)	238
Purchased resources (M)	0.41
Services and labor (S)	0.04
Emergy Yield (Y)	556
Feedback from economy (F = M S)	0.45
Biomass saved in system	21.7



Emergy indices	Parameter	Value
Transformity (Tr, sej J^{-1})	Y/Ep	1.8E5
Net emergy yiel ratio (EYR)	Y/F	1234
Emergy investiment ratio (EIR)	F/I	0.001
Enviromental loading rate (ELR)	(NF)/R	0.75
Renewability (% R)	100(R/Y)	57
Emergy exchange ratio (EER)	Y/income*3.18E12	3.05

Annex 4: Emergy analysis: explanation of the symbols



- *Energy circuit:* A pathway whose flow is proportional to the quantity in the storage or source upstream.
- *Heat sink:* Dispersion of potential energy into heat that accompanies all real transformation processes and storages; loss of potential energy from further use by the system.
- *Source:* Outside source of energy delivering forces according to a program controlled from outside; a forcing function.
- *Tank:* A compartment of energy storage within the system storing a quantity as the balance of inflows and outflows; a state variable.
- *Interaction:* Interactive intersection of two pathways coupled to produce an outflow in proportion to a function of both;control action of one flow on another; limiting factor action;work gate.
- *Producer:* Unit that collects and transforms low-quality energy under control interactions of high-quality flows.
- *Consumer:* Unit that transforms energy quality, stores it, and feeds it back autocatalytically to improve inflow.
- *Switching action:* A symbol that indicates one or more switching actions.
- *Box:* Miscellaneous symbol to use for whatever unit or function is labeled.
- *Transaction:* A unit that indicates a sale of goods or services (solid line) in exchange for payment of money (dashed line). Price is shown as an external source.
- *Constant-gain amplifier:* A unit that delivers an output in proportion to the input *I* but is changed by a constant factor as long as the energy source *S* is sufficient.
- *Self-limiting energy receiver:* A unit that has a self-limiting output when input drives are high because there is a limiting constant quality of material reacting on a circular pathway within.