Environmental Effects of Agricultural Expansion in the Upper Amazon

A Study of River Basin Geochemistry and Hydrochemistry, and Farmers' Perceptions
ENVIRONMENTAL EFFECTS OF AGRICULTURAL EXPANSION IN THE UPPER AMAZON: A STUDY OF RIVER BASIN GEOCHEMISTRY AND FARMERS' PERCEPTIONS

LINA LINDELL

LINNAEUS UNIVERSITY PRESS
ENVIRONMENTAL EFFECTS OF AGRICULTURAL EXPANSION IN THE UPPER AMAZON

A STUDY OF RIVER BASIN GEOCHEMISTRY AND HYDROCHEMISTRY, AND FARMERS’ PERCEPTIONS

LINA LINDELL

LINNAEUS UNIVERSITY PRESS
Abstract


In this thesis natural science is combined with environmental psychology in order to determine how deforestation and subsequent agricultural expansion in the Peruvian highland jungle has affected the natural environment and rural livelihoods. This region is part of one of the most biodiverse areas on Earth and is also exposed to high pressure from deforestation that threatens the ecosystems as well as the well-being of local populations. The problem stretches beyond the upper Amazon since the region constitutes headwaters to the Amazon River and is part of the most important forest ecosystem of the world.

This study evaluates the relative controls of human induced land-cover change and natural factors on the chemical status of soils, stream waters, and sediments, mainly through a spatial sampling design. The field work was located to two adjacent river basins underlain by sedimentary rocks. Streams of 48 independent sub-basins, the two main rivers, 80 upland soil sites (weakly developed soils on sandstone and siltstone) and four vertical profiles of floodplain sediments were sampled and analysed for major and trace elements, including nutrients and potentially toxic metals. Further, perceptions of environmental changes were investigated through a combination of quantitative and qualitative interview data collected from 51 smallholder farmers.

Soils of primary forests were found to be chemically similar to those of regenerated forests and agricultural land-covers (pastures and coffee plantations), and differences in chemical concentrations between streams draining areas to varying degrees covered by forest were assigned to natural variability. In addition, the chemical composition of alluvial deposits was similar in the two drainage basins despite a substantial difference in exploitation degree (30 % versus 70 % cleared from forest). Thus, no evidence was found of long-term changes in the geochemistry of the Subandean river basins as a result of the conversion of primary forest to agricultural land-uses. The farmers, however, perceived an overall increase in environmental degradation as well as a change towards drier and warmer climatic conditions. The climate change was reported to be the main factor responsible for a negative trend in life quality (rural livelihoods). The results may be used in the work of identifying priorities and key factors necessary for environmental and socioeconomic sustainability in the upper Amazon.

Keywords: tropical humid forest; deforestation; land-use change; slash-and-burn agriculture; spatial variation; vertical distribution; multielement analysis; sustainable development; climate change; rural livelihoods
Abstract


In this thesis natural science is combined with environmental psychology in order to determine how deforestation and subsequent agricultural expansion in the Peruvian highland jungle has affected the natural environment and rural livelihoods. This region is part of one of the most biodiverse areas on Earth and is also exposed to high pressure from deforestation that threatens the ecosystems as well as the well-being of local populations. The problem stretches beyond the upper Amazon since the region constitutes headwaters to the Amazon River and is part of the most important forest ecosystem of the world.

This study evaluates the relative controls of human induced land-cover change and natural factors on the chemical status of soils, stream waters, and sediments, mainly through a spatial sampling design. The field work was located to two adjacent river basins underlain by sedimentary rocks. Streams of 48 independent sub-basins, the two main rivers, 80 upland soil sites (weakly developed soils on sandstone and siltstone) and four vertical profiles of floodplain sediments were sampled and analysed for major and trace elements, including nutrients and potentially toxic metals. Further, perceptions of environmental changes were investigated through a combination of quantitative and qualitative interview data collected from 51 smallholder farmers.

Soils of primary forests were found to be chemically similar to those of regenerated forests and agricultural land-covers (pastures and coffee plantations), and differences in chemical concentrations between streams draining areas to varying degrees covered by forest were assigned to natural variability. In addition, the chemical composition of alluvial deposits was similar in the two drainage basins despite a substantial difference in exploitation degree (30 % versus 70 % cleared from forest). Thus, no evidence was found of long-term changes in the geochemistry of the Subandean river basins as a result of the conversion of primary forest to agricultural land-uses. The farmers, however, perceived an overall increase in environmental degradation as well as a change towards drier and warmer climatic conditions. The climate change was reported to be the main factor responsible for a negative trend in life quality (rural livelihoods). The results may be used in the work of identifying priorities and key factors necessary for environmental and socioeconomic sustainability in the upper Amazon.

Keywords: tropical humid forest; deforestation; land-use change; slash-and-burn agriculture; spatial variation; vertical distribution; multielement analysis; sustainable development; climate change; rural livelihoods
Resumen

En esta tesis se combina la ciencia natural con la psicología ambiental con el fin de determinar cómo la ampliación de la frontera agrícola ha afectado el medio ambiente y los medios de vida en la selva alta del Perú. Esta región forma parte de una de las zonas con mayor biodiversidad en el planeta y a su vez está expuesta a una alta presión de la deforestación que amenaza a los ecosistemas, así como el bienestar de la población en esta zona. Así mismo, este problema se hace sentir más allá de la selva alta ya que esta zona forma parte de las cabeceras del río Amazonas y pertenece al ecosistema forestal más importante del mundo.

Este estudio evalúa los efectos de la agricultura de tala y quema, en comparación con los factores naturales, sobre las propiedades químicas de los suelos, las quebradas, y los sedimentos, principalmente a través de un diseño de muestreo espacial. El trabajo de campo se realizó en dos cuencas fluviales adyacentes que están compuestas por rocas sedimentarias. Quebradas de 48 sub-cuencas independientes, dos ríos principales, 80 localidades de suelo (poco desarrollados sobre areniscas y limolitas) y cuatro perfiles verticales de sedimentos fluviales fueron muestreados y analizados para los elementos mayores y menores, incluyendo nutrientes y metales potencialmente tóxicos. También se han investigado las percepciones sobre los cambios ambientales usando una combinación de datos cuantitativos y cualitativos, recopilados a través de entrevistas a 51 agricultores.

Según los resultados no hubo diferencias significativas entre la química de suelos de bosques primarios y tierras agrícolas (pastos, plantaciones de café y de bosques secundarios). En cuanto a las quebradas, las diferencias en las concentraciones de sustancias químicas entre sub-cuencas afectadas por la deforestación en diferentes grados fueron asignados a una variabilidad natural. Además, la composición química de los depósitos aluviales fue similar en las dos cuencas a pesar de una diferencia sustancial en el grado de explotación (30 % en comparación con 70 % deforestado). Por lo tanto, no se encontró evidencia de cambios persistentes en la geoquímica de las cuencas Subandinas como resultado de la conversión de bosques a tierras agrícolas. Sin embargo los agricultores percibieron una tendencia general de aumento de la degradación del medio ambiente, así como un cambio en el clima a condiciones más secas y cálidas, lo cual fue reportado como el principal factor responsable de un cambio negativo en la calidad de vida. Estos resultados pueden ser utilizados en el trabajo de identificación de prioridades y factores claves para la sostenibilidad ambiental y socioeconómica en la selva alta.

Palabras claves: bosque húmedo tropical; deforestación; cambios de uso de la tierra; agricultura de tala y quema; variabilidad espacial; distribución vertical; análisis multieelemental; desarrollo sostenible; cambio climático; sustentos rurales
En esta tesis se combina la ciencia natural con la psicología ambiental con el fin de determinar cómo la ampliación de la frontera agrícola ha afectado el medio ambiente y los medios de vida en la selva alta del Perú. Esta región forma parte de una de las zonas con mayor biodiversidad en el planeta y a su vez está expuesta a una alta presión de la deforestación que amenaza a los ecosistemas, así como el bienestar de la población en esta zona. Así mismo, este problema se hace sentir más allá de la selva alta ya que esta zona forma parte de las cabeceras del río Amazonas y pertenece al ecosistema forestal más importante del mundo.

Este estudio evalúa los efectos de la agricultura de tala y quema, en comparación con los factores naturales, sobre las propiedades químicas de los suelos, las quebradas, y los sedimentos, principalmente a través de un diseño de muestreo espacial. El trabajo de campo se realizó en dos cuencas fluviales adyacentes que están compuestas por rocas sedimentarias. Quebradas de 48 sub-cuencas independientes, dos ríos principales, 80 localidades de suelo (poco desarrollados sobre areniscas y limolitas) y cuatro perfiles verticales de sedimentos fluviales fueron muestreados y analizados para los elementos mayores y menores, incluyendo nutrientes y metales potencialmente tóxicos. También se han investigado las percepciones sobre los cambios ambientales usando una combinación de datos cuantitativos y cualitativos, recopilados a través de entrevistas a 51 agricultores.

Según los resultados no hubo diferencias significativas entre la química de suelos de bosques primarios y tierras agrícolas (pastos, plantaciones de café y de bosques secundarios). En cuanto a las quebradas, las diferencias en las concentraciones de sustancias químicas entre sub-cuencas afectadas por la deforestación en diferentes grados fueron asignados a una variabilidad natural. Además, la composición química de los depósitos aluviales fue similar en las dos cuencas a pesar de una diferencia sustancial en el grado de explotación (30% en comparación con 70% deforestado). Por lo tanto, no se encontró evidencia de cambios persistentes en la geoquímica de las cuencas Subandinas como resultado de la conversión de bosques a tierras agrícolas. Sin embargo los agricultores percibieron una tendencia general de aumento de la degradación del medio ambiente, así como un cambio en el clima a condiciones más secas y cálidas, lo cual fue reportado como el principal factor responsable de un cambio negativo en la calidad de vida. Estos resultados pueden ser utilizados en el trabajo de identificación de prioridades y factores claves para la sostenibilidad ambiental y socioeconómica en la selva alta.

Palabras claves: bosque húmedo tropical; deforestación; cambios de uso de la tierra; agricultura de tala y quema; variabilidad espacial; distribución vertical; análisis multielemental; desarrollo sostenible; cambio climático; sustentos rurales.
A mi brisita de amor anhelado
Milo Wayra,❤
,,y a toda la gente rural
der de la selva alta peruana ❤
If you do not expect the unexpected, you will not find it.

Heraclitus of Ephesus
Si no esperas lo inesperado, no lo reconocerás cuando llegue...  

Heráclito de Efeso

This year is the international year of forests, where UN encourages "Celebrating Forests for People". According to my personal opinion, I hope that future development of the highland jungle embraces the natural diversity of the region, and follows this alternative path to progress as opposed to stepping into the same footsteps as many other more industrialized parts of the world. I fear that with continued deforestation follows not only loss of trees and degradation of waters and soils but also a loss of the very soul, or if you wish identity, of the highland jungle which I believe is part of its uniqueness and strengths and one of the factors that encompass the well-being of its people.
This year is the international year of forests, where UN encourages “Celebrating Forests for People”. According to my personal opinion, I hope that future development of the highland jungle embraces the natural diversity of the region, and follows this alternative path to progress as opposed to stepping into the same footsteps as many other more industrialized parts of the world. I fear that with continued deforestation follows not only loss of trees and degradation of waters and soils but also a loss of the very soul, or if you wish identity, of the highland jungle which I believe is part of its uniqueness and strengths and one of the factors that encompass the well-being of its people.
Este año es el año International de los bosques, por lo cual la ONU invita a celebrar “los Bosques para la Gente”. Según mi opinión espero que el desarrollo futuro de la selva alta abarque la diversidad natural de la región, y que siga este camino alternativo para el progreso en vez de repetir el mismo camino de muchas otras regiones más industrializadas del mundo. Temo que la continua deforestación no sólo lleve a la pérdida de los árboles y la degradación de las aguas y los suelos, sino que además contribuya a la pérdida del espíritu o la identidad de la selva alta, la cual es parte de su valiosa y única característica. Además creo que es uno de los factores que comprende el bienestar de su gente.
Proem

One sunny day my life changed- and it would never be the same again.

A young man, full of energy and expectations left his place here on Earth, all too soon. They said he was wanted by the Yacumama, the mother of the lakes, rivers and swamps. In a place so beautiful she called for him, the moment after he was forever gone. It was dramatic.

In my memory is glued the image of him, lying on top of the roof of an ambulance, the sirens were loud, very. Dense forest flew by the windows, it seemed calm and unaffected by our being. Blood was running in trickles along the window screens. It was a nightmare.

Only a few days after my eyes would meet a set of others, dark and at the moment full of sadness. My heart would forever be lost, with unconditional love, to them.

I did not know then that I would devote several years of my life to exploring the very landscape that was passing by the windows of that ambulance, including some of the dwellings of the big mother snake.

Over the years, my respect for the worldview and beliefs of the people of the upper Amazon has grown, I have grown.

Lina
# TABLE OF CONTENTS

List of publications ........................................................................................................ 1

1. Introduction ............................................................................................................. 2
   1.1 This thesis ........................................................................................................ 2
   1.2 Deforestation and land use change ............................................................... 5
   1.3 Peruvian highland jungle in an Amazon context ........................................... 6
   1.4 Chemical effects of slash and burn ............................................................... 9

2. Aim ............................................................................................................................ 12

3. Methodology ........................................................................................................... 13
   3.1 Concepts and approaches ............................................................................. 13
      3.1.1 River basin .......................................................................................... 13
      3.1.2 Spatial and temporal study design ....................................................... 14
      3.1.3 Data control and statistical analysis ................................................... 17
   3.2 Study areas ...................................................................................................... 20
   3.3 Upland soils ..................................................................................................... 24
   3.4 Surface water and sub-basin physical properties ......................................... 30
   3.5 Floodplain sediments ................................................................................... 36
   3.6 People ............................................................................................................. 43

4. Findings .................................................................................................................... 47
   4.1 River basin chemical characteristics ........................................................... 47
   4.2 Environmental changes .................................................................................. 50
      4.2.1 Migration of people ............................................................................. 50
      4.2.2 Forest cover ......................................................................................... 50
      4.2.3 Soil quality ............................................................................................ 51
      4.2.4 Water quality ....................................................................................... 58
      4.2.5 Basin-wide chemical processes ......................................................... 61
      4.2.6 Livelihoods (forest products, climate & water quantity) .................... 66

5. Conclusions .............................................................................................................. 71
   Recommendations .................................................................................................. 74
   Prologue and gratitude ............................................................................................ 78
   References ............................................................................................................. 83

Appendix 1  Errata
Appendix 2  Student Reports
Appendix 3  Awarded Grants
Appendix 4  Assisting Colleagues
LIST OF PUBLICATIONS

Journal articles


IV Lindell, L., Henningsson, M., Åström, M.E. Farmers’ perception of environmental changes in the upper Amazon, Peru. *Manuscript.*

Extended abstracts (peer reviewed)


¹ Reprinted with permission from Elsevier.
1. INTRODUCTION

1.1 This thesis

This thesis was elaborated between the years of 2005 and 2011. The content is based on three published papers and one submitted manuscript (Paper I-IV). Throughout this thesis focus is on the San Martin region in the Peruvian highland jungle where field work was conducted mainly in 2005 (2 months) and in 2007 (4 months; Figure 1.1). The research topic of the thesis was elaborated based on knowledge learned from a university course in rural development held in San Martin in 2002. In this section an introduction is given to the research issue in general and thereafter follows the methodology and results of the four subprojects. For further details on each individual study refer to the articles presented in the second part of this book. A list of errata for the journal articles can be found in Appendix 1.

Apart from the publications in scientific journals results have been reported to local stake-holders foremost through an oral presentation at a Peruvian congress on tropical soils held in Tarapoto 2008, and technical orientations given in several rural villages (in 2005, 2007, 2008, and 2011). In addition, printed summaries have been handed out and farmers involved in the study on soils have received their chemical data sets. Within the scope of the thesis five minor field studies funded by Sida (Swedish International Development Cooperation Agency), which also served as Master theses, were supervised (Appendix 2). In addition to the basic funding from the Linnaeus University in Kalmar, Sweden, and Nova FoU Research and Development Platform in Oskarshamn, Sweden, this thesis received additional support from a number of grants (Appendix 3). It was also supported in various ways by a range of organisations (Appendix 4). The photographs included in the thesis were taken by the author or one of the students or assistants in the sampling team.

2 Conditions for Sustainable Rural Livelihoods - a Comparative Village Study, Sweden – Peru, Swedish University of Agricultural Sciences, Uppsala.
1. INTRODUCTION

1.1 This thesis

This thesis was elaborated between the years of 2005 and 2011. The content is based on three published papers and one submitted manuscript (Paper I-IV). Throughout this thesis focus is on the San Martin region in the Peruvian highland jungle where field work was conducted mainly in 2005 (2 months) and in 2007 (4 months; Figure 1.1). The research topic of the thesis was elaborated based on knowledge learned from a university course in rural development held in San Martin in 2002. In this section an introduction is given to the research issue in general and thereafter follows the methodology and results of the four subprojects. For further details on each individual study refer to the articles presented in the second part of this book. A list of errata for the journal articles can be found in Appendix 1.

Apart from the publications in scientific journals results have been reported to local stakeholders foremost through an oral presentation at a Peruvian congress on tropical soils held in Tarapoto 2008, and technical orientations given in several rural villages (in 2005, 2007, 2008, and 2011). In addition, printed summaries have been handed out and farmers involved in the study on soils have received their chemical data sets. Within the scope of the thesis five minor field studies funded by Sida (Swedish International Development Cooperation Agency), which also served as Master theses, were supervised (Appendix 2). In addition to the basic funding from the Linnaeus University in Kalmar, Sweden, and Nova FoU Research and Development Platform in Oskarshamn, Sweden, this thesis received additional support from a number of grants (Appendix 3). It was also supported in various ways by a range of organisations (Appendix 4). The photographs included in the thesis were taken by the author or one of the students or assistants in the sampling team.

2 Conditions for Sustainable Rural Livelihoods - a Comparative Village Study, Sweden – Peru, Swedish University of Agricultural Sciences, Uppsala.

---

Figure 1.1 Location of the area in focus of the thesis. San Martin region with the river basins of Sisa (east) and Saposoa (left) marked (thin grey lines). The western limit of the Amazon Basin is marked (thick grey line). Names of major rivers (brown) are written in italic font. Source of the shaded relief image: ESRI Data & Maps 2000

Figure 1.2 Current (left) and original (right) forest cover in the upper part of Latin America. Light green areas are degraded (non-intact) forest while dark green areas are natural (intact) ecosystems. Source: Bryant et al. 1997
1.2 Deforestation and land use change

Ever since man settled down and left nomad livelihood in favour to agricultural production we have continuously reshaped our natural environment. This has given rise to human induced changes over the globe. Regarding vegetation, it is estimated that as much as 50% of the forest that once covered Earth now is gone (i.e. in pre-agricultural times; Bryant et al. 1997).

Over the years there has been a large spread in reported estimates of deforested extents and deforestation rates. The differences in reported numbers are influenced by several factors. For example differences in the following: source of information (remote sensing versus statistical data), resolution and quality of satellite images used, sensor specific characteristics and methodology used for pixel classification, definitions used to classify mapped forest, e.g. forest type to be included, minimum size of forest areas and minimum degree of canopy cover, spatial extents of analysed areas and periods for which deforestation rates are calculated. These sources of bias have to be taken into account when evaluating absolute and relative figures on deforestation. In the assessment on the state of the world's forests carried out by UN, areas with as little as just above 10% of tree cover are classified as forest. According to their latest assessment there is an increase in forest cover in terms of temperate and boreal forests while there is a continuous decrease in the extent of tropical forests (FAO 2011b). The clearing of tropical forest has largely been carried out since the 1960s (Rudel et al. 2009). Over the last decade Latin America and the Caribbean had the highest net forest loss (FAO 2011a). The current forest cover of this region compared to the estimated pre-agricultural extent is illustrated in Figure 1.2. In addition to forest clearing there is an associated degradation of the remaining forest including fragmentation and edge effects. Broadbent et al. (2008) reported that the magnitude of forest degradation as a result of selective logging (i.e. removal of valuable hardwood species) in the Brazilian Amazon is as large as that of the forest clearing. This indicates that to encompass total forest degradation the data on forest clearing may have to be doubled. Thus, tropical forests are in a process of severe degradation and deforestation rates are overall “alarmingly high” (FAO 2011b). On a global level the principal drivers are subsistence farming (48%), commercial agriculture (32%) and wood extraction (19%; UNFCCC 2007). Rudel et al. (2009) showed that in tropical areas the pressure and relative importance from commercial large-scale farms, loggers and the international markets have increased substantially post 1990. The reduction of the forests of the Amazon Basin is of particular concern. Deforestation to open up for agricultural land is currently ongoing and intense. Croplands and cattle pastures are extended into areas previously covered by sensitive and complex ecosystems of humid tropical forests. The inadequate management of Amazonian natural resources is a serious threat to the Amazon ecosystem as well as to global sustainability. It causes loss of

Figure 1.4 Tarapoto “The city of palms” (La ciudad de las palmeras), surrounded by the mountains rich in mosses and ferns, in 1856 (left) and in the 2009 (right) with 12 000 and 117 000 inhabitants respectively. Source: part of drawing by Spruce R. (1908) and Lindell L. (2009)

Figure 1.5 Conceptual model of the effects of slash and burn largely based on Giardinia et al. 2000b. Brown area represents overburden.
1.2 Deforestation and land use change

Ever since man settled down and left nomad livelihood in favour to agricultural production we have continuously reshaped our natural environment. This has given rise to human induced changes over the globe. Regarding vegetation, it is estimated that as much as 50% of the forest that once covered Earth now is gone (i.e. in pre-agricultural times; Bryant et al. 1997). Over the years there has been a large spread in reported estimates of deforested extents and deforestation rates. The differences in reported numbers are influenced by several factors. For example differences in the following: source of information (remote sensing versus statistical data), resolution and quality of satellite images used, sensor specific characteristics and methodology used for pixel classification, definitions used to classify mapped forest, e.g. forest type to be included, minimum size of forest areas and minimum degree of canopy cover, spatial extents of analysed areas and periods for which deforestation rates are calculated. These sources of bias have to be taken into account when evaluating absolute and relative figures on deforestation. In the assessment on the state of the world’s forests carried out by UN, areas with as little as just above 10% of tree cover are classified as forest. According to their latest assessment there is an increase in forest cover in terms of temperate and boreal forests while there is a continuous decrease in the extent of tropical forests (FAO 2011b). The clearing of tropical forest has largely been carried out since the 1960s (Rudel et al. 2009). Over the last decade Latin America and the Caribbean had the highest net forest loss (FAO 2011a). The current forest cover of this region compared to the estimated pre-agricultural extent is illustrated in Figure 1.2. In addition to forest clearing there is an associated degradation of the remaining forest including fragmentation and edge effects. Broadbent et al. (2008) reported that the magnitude of forest degradation as a result of selective logging (i.e. removal of valuable hardwood species) in the Brazilian Amazon is as large as that of the forest clearing. This indicates that to encompass total forest degradation the data on forest clearing may have to be doubled. Thus, tropical forests are in a process of severe degradation and deforestation rates are overall “alarmingly high” (FAO 2011b). On a global level the principal drivers are subsistence farming (48%), commercial agriculture (32%) and wood extraction (19%; UNFCCC 2007). Rudel et al. (2009) showed that in tropical areas the pressure and relative importance from commercial large-scale farms, loggers and the international markets have increased substantially post 1990.

The reduction of the forests of the Amazon Basin is of particular concern. Deforestation to open up for agricultural land is currently ongoing and intense. Croplands and cattle pastures are extended into areas previously covered by sensitive and complex ecosystems of humid tropical forests. The inadequate management of Amazonian natural resources is a serious threat to the Amazon ecosystem as well as to global sustainability. It causes loss of
genetic diversity and degradation of land and waters with severe effects on local natural environments and livelihoods (see for example Barthem et al. 2004; Martins et al. 1991; McClain 2001). The deforestation directly affects traditional harvesting of forest products, fish and wild game. Habitat modification, or loss of ecosystems, including community structure and species composition is often unplanned and constitutes the main factor responsible for extensive economic, social and health problems throughout the Amazon Basin (Barthem et al. 2004). These difficulties frequently result in social conflicts. In Peru for example, nearly 50 % of the social conflicts are related to the natural environment and often involve issues related to use and access of natural resources (Peruvian human rights ombudsman 2011). The consequences of the decline in forest cover stretch far beyond the Amazon region. Because of the unique function of the Amazon forest, in particular its intimate relation to the global hydrological circulation and global gas fluxes, it has profound effects on the well-being of the planet. Through its exchange of gases with the atmosphere it has great impact on the rate of climate change and the amount and distribution of rain fall (D’Almeida et al. 2007; Salimon et al. 2004).

1.3 Peruvian highland jungle in an Amazon context

One of the actively expanding deforestation fronts threatening the forest ecosystems of the Amazon Basin is situated along the foothills of the eastern Andes (Achard et al., 1998; Myers, 1993; Lepers et al., 2005). The region of highland jungle (selva alta) constitutes the area where the rugged peaks of the Eastern Andean mountain range gradually transforms in to the vast lowlands of the Amazon plain (Figure 1.1). This upper (western) part of the Amazon constitutes headwater areas for many of the largest rivers of the basin, including the mighty Amazon River. The Andean Amazon is geologically young, petrologically diverse and tectonically active and has a major influence on the hydrogeochemistry of downstream areas of the Amazon Basin (Stallard, 2002). It is a massive supplier of soluble and suspended materials to streams and rivers and in downstream areas it is the main source of river-transported chemical and physical components (Gibbs, 1967). In the mouth of the Amazon River more than 80 % of the total dissolved salts and the total suspended solids originate from the Andes despite that it accounts for only little more than 10 % of the total basin area. Thus, deforestation and land use change in the Andean Amazon has the potential to significantly alter both local and regional hydrochemical and hydrophysical conditions. However, despite its importance it has so far received relatively little attention in scientific contexts.

Peru is one of the countries with the largest holdings of humid tropical forest in the world (4th place globally and 2nd of Amazon forest; FAO 2011a). One of the Peruvian regions largely located to highland jungle is San Martin
One of the countries with the largest holdings of humid tropical forest of the Amazon plain (Figure 1.1). This upper (western) part of the Amazon despite its importance it has so far received relatively little attention in local and regional hydrochemical and hydrophysical conditions. However, change in the Andean Amazon has the potential to significantly alter both the Amazon River more than 80% of the total dissolved salts and the total transported chemical and physical components (Gibbs, 1967). In the mouth of streams and rivers and in downstream areas it is the main source of river - (Stallard, 2002) . It is a massive supplier of soluble and suspended materials to on the hydrogeochemistry of downstream areas of the Amazon Basin young, petrologically diverse and tectonically active and has a major influence the unique function of the Amazon forest, in particular its intimate relation to the decline in forest cover stretch far beyond the Amazon region. Because of including the mighty Amazon River. The Andean Amazon is geologically and distribution of rain fall (D’Almeida et al. 2007; Salimon et al. 2004). These difficulties frequently result in social conflicts. In extensive economic, social and health problems throughout the Amazon Basin composition is often unplanned and constitutes the main factor responsible for modification, or loss of ecosystems, including community structure and species traditional harvesting of forest products, fish and wild game. Habitat 2004; Martins et al. 1991; McClain 2001). The deforestation directly affects genetic diversity and degradation of land and waters with severe effects on resources (Peruvian human rights ombudsman 2011) . The consequences of environment and often involve issues related to use and access of natural Peru for example, nearly 50% of the social conflicts are related to the natural Eastern Andean mountain range  gradually transforms in to the vast lowlands and mesas and mountains have given rise to a particularly rich diversity in plant and animal species. Many of the mountain slopes, such as the ones part of this thesis, belong to the Peruvian Yungas ecoregion. These forests are classified as making part of the richest terrestrial area on Earth (Tropical Andes; Mittermeier et al. 2004).

Traditionally, indigenous populations sustained themselves by small-scale slash and burn agriculture (i.e swidden farming), hunting and fishing. In the view of the Kechwa-lamistas, one of the local indigenous groups, people and the environment as well as the spirits are part of a unity “sacha”. Thus, land can not belong to a human being but is part of this collective (Rengifo et al. 1993). This worldview is clearly distinct from today’s highly resource oriented. Farming plots were small, since forest was not exploited to a larger degree than necessary to uphold subsistence, and imitated the characteristics of the jungle. Even today traditional farmers may keep over 50 different crop varieties within 1 ha (Rengifo 2007).

Slash and burn of the original forest cover to open up for agricultural land has thus occurred for centuries but the process has been particularly intense over the last four decades. In fact, the principal drive for deforestation in this part of the Amazon is small-scale subsistence agriculture (Achard et al. 1998) and at present, farmers claim increasingly inaccessible and steep sloping land in remote headwater areas bordering intact forest. The region has converted into an agricultural centre where forest has been forced to give way for cropping land and pastures. Extensive areas of the natural vegetation composed of dense evergreen forest have been converted to a mosaic of agricultural crops (maize, coffee, plantain, rice and cacao), pastures and secondary vegetation and irregularly distributed patches of primary forest. Slash and burn is applied in an unsustainable manner with no or short duration of fallow which has resulted in extensive areas of degraded, abandoned land. According to the Amazonian Research Institute, IIAP, only 20% of the total deforested land in San Martin is used for agricultural production (Ramírez 2004).
The pressure on the environment continuously increases due to population growth partly caused by an inflow of colonist farmers driven by inadequate livelihood conditions and social difficulties in their native regions (high Andes and coastal areas). Already in pre-Hispanic times there were internal migration between different ecological regions of Peru. However, during the latter part of the last century the inflow of new settlers to the mountainous jungle, the process of “selvatización”, was particularly intense and stimulated foremost by the coca boom. Until 1995 the region was the world’s first producer of coca and the main production was located to the Huallaga valley (UNODC 2003; Figure 1.1). Other contributing causes are road constructions and political incentives for agricultural expansion (Limachi 2004). Consequently, for long periods San Martin has been one of the regions with a positive net migration and rural population increase (Figure 1.3). From the early seventies to the early nineties the annual population growth was ≥4% (INEI 2008). The change over the last 150 years in the scenery of Tarapoto, the largest city in the region, is illustrated in Figure 1.4 (see Figure 1.1 for its geographical location). The increased population put a severe pressure on the forests which consequently for a long time has suffered from the highest deforestation rates in Peru. At the beginning of this century approximately 30 % (13,300 km²) of its original forest cover had been cleared (Reategui & Martinez 2004). Even though the current positive net amount of immigrants is lower than it has been before the absolute amount of new settlers is likely an important factor in the expansion of agricultural areas in to intact forest zones since “used” land often is abandoned instead of being recuperated and cultivated. The new settlers purchase or claim land to begin their new life in the lush and expectedly productive jungle. When a sufficient number of families have accumulated in the same area they form communities that later turn into villages and cities throughout the jungle. Many of the names given to these new places reveal the

---

3 In Peru, the amount of degraded pre-montane forest as a direct result of coca cultivations may amount to 1,000,000 ha (Young 1996).
The beginning of this century approximately 30% (13,300 km²) of its original forest cover had been cleared (Reategui & Martinez 2004). Even though the current positive net amount of immigrants is lower than it has been before the land was abandoned instead of being recuperated and cultivated. The new settlers of agricultural areas in to intact forest zones since “used” land often is not abandoned but instead is continuously cultivated. As the absolute amount of new settlers is likely an important factor in the expansion of agricultural land use, the latter part of the last century the inflow of new settlers to the mountainous jungle, the process of “selvatización”, has been one of the regions with a positive net migration and rural population increase (Figure 1.3). From the early seventies to the early nineties Martin has been one of the regions with a positive net migration and rural population increase (INEI 2008). The change over the last 150 years in the scenery of Tarapoto, the largest city in the region, is shown to improve soil fertility by restoring nutrient levels (Farella et al. 2007; Hölscher et al. 1997; Müller et al. 2004) or possibly more (Reiners et al. 1994). Eventually agricultural land uses cause a decline in soil productivity (Martins et al. 1991). The degradation of soils have been attributed to decreases in C and N (Murty et al. 2002) and loss of other important plant nutrients by leaching and increased surface runoff and erosion (McDonald et al. 2002; Abe et al. 2007; Mainville et al. 2006; Parker 1985; Williams et al. 1997). The elevated export of solids and solutes have been documented in soil water, ground water and surface water (Parker 1985; Williams et al. 1997; Ballester et al. 2003; Forti et al. 2000; Williams et al. 1997). In contrast to the degradation of soils under agricultural use regenerating vegetation has shown to improve soil fertility by restoring nutrient levels (Farella et al. 2007; Hölscher et al. 1997; Gong et al. 2006; Templer et al. 2005). Few investigations within the Amazon basin have so far focused on the effects on trace element dynamics where potentially toxic metals (e.g., Cd, Pb, Hg, Cr, Cu, Co, As and Ni) are of particular concern. Several studies have shown a
significant release of Hg from soils following deforestation (Mainville et al. 2006; Roulet et al. 2000; Fostier et al. 2000). Elevated Hg concentrations have also been detected in fish and in human hair from riverine populations consuming it (Maurice-Bourgoin et al. 1999; Gammons et al. 2006). There are also indications of increases in concentrations of other trace element (e.g., Cu, Pb, Ni and As) in soils after forest conversion to pasture (Abe et al. 2007; Herpin et al. 2002). In addition, Seyler & Boaventura (2001) report that forest fires are an important source of several trace metals (e.g. Cr, Cu, Mn, Ni, Pb, V, As, and Zn).

The above described processes taking place following deforestation and burning is a simplification of the diversity in responses. First, the majority of published studies have been investigating the effects of forest conversion to cattle pasture on nutrient levels in surface soils of the Amazon lowland (i.e. foremost on acid and nutrient poor Oxisols and Ultisols). In contrast, there is limited information regarding effects on soils in mountainous environments, on eutric soils, and on soils of other land covers than pasture such as crops and forest regrowth. Second, the influence of deforestation disturbances and burning on soil nutrient dynamics are highly site specific and complex and depend on various factors such as soil order, soil texture, topography, land management history pre-burn and time elapsed since last burn, climate, particular crops or for pasture particular species used, presence of cattle, fire intensity at burn and post-burn weather conditions etc. (Numata et al. 2007; Holmes et al. 2006; Jordan 1985; Lu et al. 2002; Hölscher et al. 1997). For example, Farella et al. (2007) found different soil responses to slash and burn to be attributable to soil texture. While median Ca, K and Mg was higher in all agricultural soils compared to forest soils, C and organic P showed contrasting patterns in soils of different clay content. In the study by Numata et al. (2007) differences in the response from forest conversion to pasture were assigned to differences in pre-disturbance soil pH. The development of chemical characteristics over time were different between Alfisols (higher pH, more fertile) compared to Oxisols and Ultisols. The results by Vera et al. (2007) demonstrate that soil order may be insufficient to distinguish between soils exhibiting different responses to deforestation and land use change. Thus, the results from studies carried out in the Amazon lowland cannot readily be extrapolated to other areas such as the Andean Amazon where lithology, geomorphology and pedology, and to a certain extent also biology and climatology differ form that of the lowland (Stallard & Edmond 1983). In this region lithology has a much greater impact on the soils because of their young age which results in a much higher inherent nutrient content compared to the old and intensively weathered soils of the lowland. The steep topography also make the soils in the upper Amazon more prone to surface erosion processes and hydrological pathways are more rapid (Alegre et al. 1990; McDonald et al. 2002).
Apart from the study by McGrath et al. (2001), that is based on 39 studies mainly carried out in the Amazon lowland, 22 published studies on land use change in the tropics were reviewed in the work of this thesis. In total, forest conversion to agricultural land uses was found to most frequently cause increases in pH, Ca, K and Mg and decreases in levels of exchangeable Al (Al\text{ex}) and also in total organic carbon (TOC), N\text{tot} and cation exchange capacity (CEC). For available P the effects were not clear with approximately equal number of studies showing decreases as no changes. When the results were separated between upland and lowland environments it was shown that the increases in pH and base cations as well as the decreases in free Al mostly were accounted for by lowland soils (dominated by Amazon studies) while the decreases in TOC and CEC were more clear in studies reported from upland settings (globally distributed). See Table 1.1 for details on the number of studies reporting on each variable. While this review is very limited and includes studies applying different methodologies it illustrates the overall varying responses from changes in land cover and land use between different sites and also indicate on differences in responses between lowland and highland settings.

Table 1.1 Results from a review\(^1\) of chemical effects from forest conversion to agriculture

<table>
<thead>
<tr>
<th>Variable</th>
<th>Lowland ((n\text{max}=13))</th>
<th>Upland ((n\text{max}=11))</th>
</tr>
</thead>
<tbody>
<tr>
<td>BS</td>
<td>↑ 2 ↓ 1 ←− ←− ↑ 1 ←−</td>
<td></td>
</tr>
<tr>
<td>pH</td>
<td>9 0 0 0 1 3</td>
<td>0 0 0 0 0 0</td>
</tr>
<tr>
<td>Ca</td>
<td>7 2 1 1 3 0</td>
<td>0 0 0 0 0 0</td>
</tr>
<tr>
<td>K</td>
<td>9 1 0 2 3 0</td>
<td>0 0 0 0 0 0</td>
</tr>
<tr>
<td>Mg</td>
<td>7 2 2 1 2 1</td>
<td>0 0 0 0 0 0</td>
</tr>
<tr>
<td>Al\text{ex}</td>
<td>0 6 3 0 0 0</td>
<td>0 0 0 0 0 0</td>
</tr>
<tr>
<td>CEC</td>
<td>1 1 0 0 0 0</td>
<td>1 1 0 0 0 0</td>
</tr>
<tr>
<td>TOC</td>
<td>4 4 3 0 0 0</td>
<td>0 0 0 0 0 0</td>
</tr>
<tr>
<td>N\text{tot}</td>
<td>1 5 2 1 6 0</td>
<td>0 0 0 0 0 0</td>
</tr>
<tr>
<td>NO\text{3}</td>
<td>2 3 0 0 0 0</td>
<td>0 0 0 0 0 0</td>
</tr>
<tr>
<td>P\text{available}</td>
<td>1 2 3 2 3 3</td>
<td>0 0 0 0 0 0</td>
</tr>
<tr>
<td>Bulk density</td>
<td>6 0 0 2 0 0</td>
<td>0 0 0 0 0 0</td>
</tr>
</tbody>
</table>

Arrows show increase (↑), decrease (↓) and no change (←−) on contradictory between sites: ←−

2. AIM

The overall aim of this thesis was to investigate how the conversion of tropical humid forest to agricultural land uses, that has occurred largely over the last 100 years, has affected the natural environment of the Peruvian mountain jungle (selva alta), a headwater area of the western (upper) Amazon Basin.

In detail, with respect to geochemistry and hydrochemistry the objective was to determine the effects of human-induced changes in land cover, in relation to natural controls, on concentrations of chemical constituents in upland soils (Paper I), rivers and streams (Paper II), and floodplain sediments (Paper III).

Concerning the interplay between humans and the natural environment (Paper IV) the objective was to determine how rural people, sustained by small-scale farming, perceive the degree and nature of the changes that have been induced as a result from deforestation and how it has affected local livelihoods.
3. METHODOLOGY

3.1 Concepts and approaches

3.1.1 River basin
To meet the stated aim of this thesis (Section 2), two river basins of the Peruvian highland jungle were selected. These river basins served as natural laboratories and are confined by the water divides of their main rivers, Sisa and Saposoa (Figure 1.1 and 3.2). Working in two adjacent river basins of similar characteristics (refer to Section 3.2 for details), a kind of paired-basin approach, allowed for comparisons between the two areas and thus served for validation of the results.

A holistic approach was pursued where potential effects of swidden farming were investigated from the source, slashing and burning of forest and subsequent land use, at upland soils (Paper I), via stream and river waters formed by surface runoff and infiltrating rainwater draining these areas (Paper II), to the outlets of the basins where river valleys are filled by alluvial sediments composed by upstream material deposited at floods (Paper III). In addition, perceptions and opinions on environmental issues were investigated through interviews with the local inhabitants, whom correspond to the main agents in the process of slash and burn (Paper IV). The themes encompassed within the thesis are illustrated in Figure 3.1.
3.1.2 Spatial and temporal study design

In the fields of hydrochemistry and geochemistry both spatial and temporal approaches are commonly applied and are considered equally important. The relative usefulness of the two methodologies varies with the character of the study. In this thesis spatial sampling was in focus when studying stream water and upland soils (Paper I and II). Several extensive projects have successfully demonstrated that spatial geochemical sampling produce highly valuable results (see for example De Vos et al. 2006; Salminen et al. 2004). Spatial data enables the identification of regional geochemical patterns of individual elements and co-variations between elements which facilitate the understanding of both regional and local geochemical processes.

Methodological procedures for sampling of natural media carried out within this thesis were in principal according to the recommendations given in the large scale spatial sampling program of the Forum of European Geological Surveys, FOREGS, and of the Barents Ecogeochemistry project (Salminen, et al. 2005; Salminen et al. 1998; Gregorauskiene et al. 2000). A few modifications were undertaken to adapt the procedures to the particular setting of this study. Research studies with a spatial approach to investigate hydrochemical variations in an Amazon setting are for example those of Elbaz-Poulichet et al. (1999) and Sobieraj et al. (2002), and studies with a special focus on the relative influence from human and natural sources, similar to that of this thesis, have been performed by Ballester et al. (2003), and Biggs et al. (2002; 2004). In terms of human induced changes on the fertility of Amazonian soils where the chemical status of used land, most commonly pasture, is compared with nearby forest soil has previously been applied by Farella et al. (2007), Mainville et al. (2006), Neill et al. (1997) and Numata et al. (2007).

Temporal changes were in focus in the studies on sediments and farmer perceptions (Paper III and IV). Because historical data from the region are very scarce floodplain sediments, in which vertical distributions of elements with depth gives an indication on the variation in basin wide geochemical processes over time, were studied (see Section 3.5 for more information). This approach has been found to produce important data in European settings which is demonstrated in the review by Bölviken et. al (2004) but is not known to have been carried out in the Amazon. Spatial variations in superficial sediments throughout the Peruvian Amazon have previously been documented in the work of Kalliola et al. (1993).

Information on how environmental conditions have changed over time can also be retrieved through interaction with local inhabitants. They have over the years accumulated information on processes in the environment and may
Methodological procedures for sampling of natural media carried out within this thesis were in principal according to the recommendations given in the large scale spatial sampling program of the Forum of European Geological Surveys, FOREGS, and of the Barents Ecogeochmistry project (Salminen, et al. 2005; Salminen et al. 1998; Gregorauksiene et al. 2000). A few modifications were undertaken to adapt the procedures to the particular setting of this study. Research studies with a spatial approach to investigate hydrochemical variations in an Amazon setting are for example those of Elbaz-Poulitchet et al. (1999) and Sobieraj et al. (2002), and studies with a special focus on the relative influence from human and natural sources, similar to that of this thesis, have been performed by Ballester et al. (2003), and Biggs et al. (2002; 2004). In terms of human induced changes on the fertility of Amazonian soils where the chemical status of used land, most commonly pasture, is compared with nearby forest soil has previously been applied by Farella et al. (2007), Mainville et al. (2006), Neill et al. (1997) and Numata et al. (2007).

Temporal changes were in focus in the studies on sediments and farmer perceptions (Paper III and IV). Because historical data from the region are very scarce floodplain sediments, in which vertical distributions of elements with depth gives an indication on the variation in basin wide geochemical processes over time, were studied (see Section 3.5 for more information). This approach has been found to produce important data in European settings which is demonstrated in the review by Bölviken et. al (2004) but is not known to have been carried out in the Amazon. Spatial variations in superficial sediments throughout the Peruvian Amazon have previously been documented in the work of Kalliola et al. (1993).

Information on how environmental conditions have changed over time can also be retrieved through interaction with local inhabitants. They have over the years accumulated information on processes in the environment and may
thus serve as a living data archive holding for example information on how environmental condition have changed over time. This information may be used to estimate or to complement measured data on environmental media and could prove particularly valuable in areas where these data are of low quality or scarce, such as the area in focus of this thesis. Paper IV is based entirely on interviews and information from local inhabitants was also retrieved to obtain important complementary information for Paper II and III (Table 3.1)

### Table 3.2 Univariate statistical analyses carried out in this thesis

<table>
<thead>
<tr>
<th>Data tested for differences</th>
<th>Groups</th>
<th>Statistical method</th>
</tr>
</thead>
</table>
| Soil chemical and physical variables¹ (Paper I, III) | * Sisa vs Saposoa  
* topsoil vs subsoil  
* older vs younger pastures  
* older vs younger coffee plantations  
* older vs younger secondary forests  
* soil of 5 land cover classes (primary forest, swidden fields, pastures, coffee plantations, secondary forest) | Mann Whitney |
| Ash chemical variables¹ (Paper I) | * ash vs chemical conc. in top soil | Mann Whitney |
| Water chemical and physical variables¹ (Paper II) | * Sisa vs Saposoa  
* > 50 % forest cover vs. < 50 % | Mann Whitney |
| Sediment chemical and physical variables¹ (Paper III) | * Sisa vs Saposoa  
* Sisa and Saposoa vs Huallaga | Mann Whitney |
| Peoples' perceptions and attitudes (Paper IV) | * native vs colonist farmers  
* male vs female farmers  
* older vs younger farmers | Mann Whitney |

¹ Refer to Table 3.4 for a complete list of variables that were tested

Perceptions and attitudes of local inhabitants have previously been used to study environmental issues in different parts of the world targeting natural resources and associated themes such as forests (Silori 2007; Dolisca et al. 2007), soils (Amsalu & de Graaff 2006), waters (Tran et al. 2002), agrochemicals (Hashemi & Damalas 2011), environmental degradation (Chokor 2004), and migration (Moran-Taylor & Taylor 2010). However, despite the importance of the knowledge, perceptions and attitudes of local people in conservation work similar studies are limited in an Amazonian context. Menton (2003) has investigated perceived changes from logging on forest products and Byg & Balslev (2006) on the availability of palm trees, McClain & Cossio (2003) and McClain (2001) have investigated water use...
and importance of riparian environments and Van Holt et al. (2010) have documented perceptions on the availability of wild animals.

### 3.1.3 Data control and statistical analysis

Data on natural media (Paper I, II and III) was checked for errors and inconsistencies through analysis of duplicates and several known relationships to prevail in soils and waters such as relative amounts of different constituents. For some parameters concentrations were determined by two different laboratories which gave information on the quality of the analysis (precision). Data on human perceptions (Paper IV) was continuously evaluated during the interviews thorough comparison of qualitative and quantitative responses given to the same question.

Visual analysis (scatterplots) and Spearman's rank coefficients ($r_s$) were used to identify correlations between variables and univariate statistics were applied to

<table>
<thead>
<tr>
<th>Media</th>
<th>Predictor variables</th>
<th>Response variables</th>
<th>Statistical model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil (Paper I)</td>
<td>* land cover (primary forest, swidden fields pasture, coffee plantations, secondary forest)</td>
<td>Ca, Co, Cu, Fe, Mg, Mn, Mo, K, N, Na, P, S, Zn, NO$_3$, NH$_4$, OM, CECe, EC, pH, Ex. acidity</td>
<td>Principal component analysis (PCA) / Partial least squares regression (PLSR$^2$)</td>
</tr>
<tr>
<td></td>
<td>* field aspect (east, west)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>* field slope</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>* soil texture (sand, silt, clay)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>* location (Sisa, Saposoa)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water (Paper II)</td>
<td>sub-basin: (Sisa, Saposoa)</td>
<td>Al, As, Ba, Ca, Ca$^*$, Cl, Cu, Fe, K, Mg, Mn, Mo, Na, Na$^+$, Ni, Pb, Sb, Si, Ti, U, Zn, HCO$_3$, SO$_4$, NH$_3$, NO$_3$, PO$_4$, DOC, pH, DO, EC, TSS, water temp.</td>
<td>Principal component analysis (PCA) / Partial least squares regression (PLSR$^2$)</td>
</tr>
<tr>
<td></td>
<td>* area</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>* elevation</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>* average elevation</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>* elevation range</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>* average slope</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>* forest cover</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>* lithology (Aluvial deposits, Juanjui, Ipuruuro, Chambira, Yahuarango, Chonta, Oriente, Sarayakuillo)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>* location (Sisa, Saposoa)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* = non-saline fraction of the element.
Table 3.4 Principal sampling and analyses of natural media in this thesis.

<table>
<thead>
<tr>
<th>Media</th>
<th>Year</th>
<th>Sites</th>
<th>Samples&lt;sup&gt;1&lt;/sup&gt;</th>
<th>Measured in situ</th>
<th>Measured in lab</th>
<th>Calc.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil</td>
<td>2007 (Feb &amp; Oct)</td>
<td>80</td>
<td>250</td>
<td>soil temp., soil color (ca 18 sites in Saposoa)</td>
<td>• pH, EC, NO&lt;sub&gt;3&lt;/sub&gt;, NH&lt;sub&gt;4&lt;/sub&gt;, Ntot, TOC, texture, bulk density, mass water content</td>
<td>BS, CECe, C:N, OM</td>
</tr>
<tr>
<td>(Paper I and III)</td>
<td>(Sis: 50, Sap: 30)</td>
<td>(Sis: 100, Sap: 150)</td>
<td>(min 2, z=0-10 cm &amp; 20-30 cm, and, max 6, at z up to 60 cm, at each site)</td>
<td>• Ca, Mg, K, P and ex. acidity (weak salts)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ash</td>
<td>2007 (Feb &amp; Oct)</td>
<td>12 soil sites</td>
<td>12</td>
<td>-</td>
<td>• Al, As, Ba, Ca, Cd, Co, Cu, Fe, Hg, K, Mg, Mn, Mo, Ni, Pb, Sr and Zn (Na-acetate, ICP-MS)</td>
<td>-</td>
</tr>
<tr>
<td>(Paper I and III)</td>
<td>(Sis: 9, Sap: 3)</td>
<td>(Sis1, Sap: 1)</td>
<td></td>
<td>• Al, As, Ba, Ca, Cd, Co, Cu, Fe, Hg, K, Mg, Mn, Ni, Pb and Zn (Na-pyrophosphate, ICP-MS)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ash and sediment</td>
<td>2007 (Dec)</td>
<td>2 floodplain sites</td>
<td>6 (layer above, at and below combustion residues)</td>
<td>-</td>
<td>• as above</td>
<td>-</td>
</tr>
<tr>
<td>(Paper III)</td>
<td>(Sis1, Sap: 1)</td>
<td>(Sis: 1, Sap: 2, Hua: 1)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sediment</td>
<td>2005 (Oct &amp; Dec)</td>
<td>4</td>
<td>120</td>
<td>-</td>
<td>• As, Ca, Cd, Co, Cu, Fe, Hg, K, Mg, Mn, Ni, Pb and Zn (aqura regia, ICP-OES for P, ICP-MS for the rest, Hg also with CVAA)</td>
<td>OM</td>
</tr>
<tr>
<td>(Paper III)</td>
<td>(Sis: 1, Sap: 2, Hua: 1)</td>
<td>(Sis: 43, Sap: 24 &amp; 29 Hua: 24)</td>
<td></td>
<td>• As, Ca, Cd, Co, Cu, Fe, Hg, K, Mg, Mn, Ni, Pb and Zn (for a subselection Na-pyrophosphate, ICP-MS)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• TOC, CaCO&lt;sub&gt;3&lt;/sub&gt;, Sols, EC, pH, grain size distribution</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• &lt;sup&gt;137&lt;/sup&gt;Cs (Sis profile and one Sap profile)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<sup>1</sup> Excluding field replicates and lab repetitions.
### Table 3.4 Continuation (Principal sampling and analyses of natural media in this thesis.)

<table>
<thead>
<tr>
<th>Media</th>
<th>Year</th>
<th>Sites</th>
<th>Samples¹</th>
<th>Measured in situ</th>
<th>Measured in lab</th>
<th>Calc.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water (Paper II)</td>
<td>2005</td>
<td>48 sub-basin streams</td>
<td>48</td>
<td>EC, DO, pH, velocity, stream dimensions, T&lt;sub&gt;water&lt;/sub&gt;</td>
<td>Al, As, Ba, Cu, Fe, Mn, Mo, Ni, Pb, Rb, Sr, Tl, U, Zn (ICP-MS on filtered water)</td>
<td>Q&lt;sub&gt;z&lt;/sub&gt;, T&lt;sub&gt;Z&lt;/sub&gt;&lt;sup&gt;+&lt;/sup&gt;, Ca&lt;sup&gt;+&lt;/sup&gt;, Na&lt;sup&gt;+&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>(Nov, &amp; Dec)</td>
<td>(Sis: 27, Sap: 21)</td>
<td></td>
<td></td>
<td>Ca, Cl, K, Mg, Na, HCO&lt;sub&gt;3&lt;/sub&gt;, SO&lt;sub&gt;4&lt;/sub&gt;, NH&lt;sub&gt;3&lt;/sub&gt;, NO&lt;sub&gt;3&lt;/sub&gt;, PO&lt;sub&gt;4&lt;/sub&gt;</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>DOC, pH, DO, EC, TSS, Twater, turbidity, TSS.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2005</td>
<td>Along Sisa river: 4</td>
<td>4</td>
<td>as above</td>
<td>as above</td>
<td>as above</td>
</tr>
<tr>
<td></td>
<td>(Dec)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2005</td>
<td>Along Saposoa river: 4</td>
<td>19</td>
<td>as above</td>
<td>as above for November, other months no ICP-MS analysis.</td>
<td>as above</td>
</tr>
<tr>
<td></td>
<td>(Mar, Apr, May, Aug, Nov)</td>
<td>Nov, 3 other months</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2007</td>
<td>Along Shima river: 6</td>
<td>12</td>
<td>as above</td>
<td>as above</td>
<td>as above</td>
</tr>
<tr>
<td></td>
<td>(Aug, Sept)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

¹ Excluding field replicates and lab repetitions.
identify differences between defined sub-groups (Table 3.2). In parts of this thesis (Paper I and II) univariate statistics were complemented with multivariate analysis (Table 3.3). The latter approach makes it possible to simultaneously take into account co-variations between all studied chemical and physical variables and is effective when working with a large number of variables. Overall correlation patterns were investigated by principal component analysis (PCA). The results can be illustrated in a map where the relationships between the studied variables and their principal controls are visualized. This was followed up by regression models including partial least squares regression (PLRS2) and multiple linear regressions (MLR; Paper I only).

3.2 Study areas

The two studied river basin stretches in an NW-SE direction. The principal rivers, Sisa and Saposoa, are meandering so called white water rivers that discharge into the braided Huallaga River. This in turn is a tributary to the Marañon River that together with the Ucayali River becomes the Amazon (Figure 1.1). The size of each river basins is ca. 2 000 km² and elevation ranges from about 200 masl on the gently undulating floodplains up to over 3000 masl in the steep, montane areas. The studied basins make part of the Subandean thrust and fold belt, largely composed of Cenozoic sandstone and siltstone in parts rich in carbonate and evaporite deposits (Hermoza et al., 2005). The dominant geological formation of the areas where soil was sampled (Paper II) and the formation most common to exist as part of the

![Figure 3.3 Precipitation in Saposoa valley, mean monthly values 1967-2004. Source: SENAMHI. The majority of data collection for this thesis was carried out in Nov and Dec (see Table 3.4 for more details).]
identify differences between defined sub-groups (Table 3.2). In parts of this thesis (Paper I and II) univariate statistics were complemented with multivariate analysis (Table 3.3). The latter approach makes it possible to simultaneously take into account co-variations between all studied chemical and physical variables and is effective when working with a large number of variables. Overall correlation patterns were investigated by principal component analysis (PCA). The results can be illustrated in a map where the relationships between the studied variables and their principal controls are visualized. This was followed up by regression models including partial least squares regression (PLS2) and multiple linear regressions (MLR; Paper I only).

3.2 Study areas

The two studied river basin stretches in an NW-SE direction. The principal rivers, Sisa and Saposoa, are meandering so-called white water rivers that discharge into the braided Huallaga River. This in turn is a tributary to the Marañon River that together with the Ucayali River becomes the Amazon (Figure 1.1). The size of each river basin is ca. 2000 km² and elevation ranges from about 200 m amsl on the gently undulating floodplains up to over 3000 m amsl in the steep, montane areas. The studied basins make part of the Subandean thrust and fold belt, largely composed of Cenozoic sandstone and siltstone in parts rich in carbonate and evaporite deposits (Hermoza et al., 2005). The dominant geological formation of the areas where soil was sampled (Paper II) and the formation most common to exist as part of the
sub-basins drained by the studied streams is called Chambira (median 28%); in detail, this formation is composed by reddish to grayish silts interbedded with medium to coarse sandstones and a few limestones (Figure 3.4; Hermoza et al. 2005). Although mineral deposits exist in the area, there are no industrial mining or processing activities within the two basins. Soils are mainly Entisols and Inceptisols, ranging from poor (dystric) to rich (eutric) in terms of nutrient content (Escobedo, 2004; this study). Forest accounts for 30% of the land area in the Sisa basin and 70% in the Saposoa basin (Reategui & Martínez, 2004). Intact forest is mainly found in inaccessible mountainous parts of the basins.

The dominating climate is tropical hot and humid but air temperatures and precipitation varies with elevation and with geographical position (latitude and longitude). Climate is continuously drier to the south and to the east, and with decreasing altitude. The location of the meteorological station at 320 masl is shown in Figure 3.2. Mean annual air temperature measured in the Saposoa valley is 26.7°C, which vary very little over the year, while mean annual precipitation is 1500 mm (SENAMHI data years 1999–2004 and 1967–2004, respectively; Figure 3.3). In the surrounding mountains the rainfall increases up to several thousands of mm (Escobedo 2004). The precipitation follows a bimodal pattern with elevated amounts in February to April and in October to December. There is no pronounced dry season (i.e. no month has a precipitation less than 60 mm) although July and August receive the least amounts of rainfall.

In the studied areas native farmers and colonist farmers live and work side by side in small communities or villages. Most of the inhabitants of the basins, ca. 50,000 and 25,000 in Sisa and Saposoa respectively, are sustained by agriculture. While they may possess larger amounts of land they only keep on an average ca. 3 ha under production (this study) and thus commonly could be viewed as small-holders or small-scale farmers. In comparison with the regional population (i.e. that of San Martin) the rural farmers interviewed for this study are poorer, have more children and less education (Paper IV; INEI 2007). In addition, the differences in education between men and women are larger. Although many of the villages have access to piped water, electricity, health care and primary education these infrastructural and social establishments are subjected to frequent disruptions and lack of resources. Farmers produce plantain, cassava and beans for household consumption and some grow coffee, cacao, and cotton that are destined for the market while corn and rice are important for both purposes. The assortment of important foods including fruit, vegetables, fish and meat are highly limited in the small local stores. Rural houses are simple often with dirt floor and wood is used as

Figure 3.6  Village in the highland jungle with houses characteristic to a native population

Figure 3.7  Village in the highland jungle of mainly colonist farmers
sub-basins drained by the studied streams is called Chambira (median 28 %; Paper I). In detail, this formation is composed by reddish to grayish silts interbedded with medium to coarse sandstones and a few limestones (Figure 3.4; Hermoza et al. 2005). Although mineral deposits exist in the area, there are no industrial mining or processing activities within the two basins. Soils are mainly Entisols and Inceptisols, ranging from poor (dystric) to rich (eutric) in terms of nutrient content (Escobedo, 2004; this study). Forest accounts for 30 % of the land area in the Sisa basin and 70 % in the Saposoa basin (Reategui & Martinez, 2004). Intact forest is mainly found in inaccessible mountainous parts of the basins.

The dominating climate is tropical hot and humid but air temperatures and precipitation varies with elevation and with geographical position (latitude and longitude). Climate is continuously drier to the south and to the east, and with decreasing altitude. The location of the meteorological station at 320 masl is shown in Figure 3.2. Mean annual air temperature measured in the Saposoa valley is 26.7°C, which vary very little over the year, while mean annual precipitation is 1500 mm (SENAMHI data years 1999-2004 and 1967–2004, respectively; Figure 3.3). In the surrounding mountains the rainfall increases up to several thousands of mm (Escobedo 2004). The precipitation follows a bimodal pattern with elevated amounts in February to April and in October to December. There is no pronounced dry season (i.e. no month has a precipitation less than 60 mm) although July and August receive the least amounts of rainfall.

In the studied areas native farmers and colonist farmers live and work side by side in small communities or villages. Most of the inhabitants of the basins, ca. 50 000 and 25 000 in Sisa and Saposoa respectively, are sustained by agriculture. While they may possess larger amounts of land they only keep on an average ca. 3 ha under production (this study) and thus commonly could be viewed as small-holders or small-scale farmers. In comparison with the regional population (i.e. that of San Martin) the rural farmers interviewed for this study are poorer, have more children and less education (Paper IV; INEI 2007). In addition, the differences in education between men and women are larger. Although many of the villages have access to piped water, electricity, health care and primary education these infrastructural and social establishments are subjected to frequent disruptions and lack of resources. Farmers produce plantain, cassava and beans for household consumption and some grow coffee, cacao, and cotton that are destined for the market while corn and rice are important for both purposes. The assortment of important foods including fruit, vegetables, fish and meat are highly limited in the small local stores. Rural houses are simple often with dirt floor and wood is used as

4 National Meteorology and Hydrology Service (Servicio Nacional de Meteorología e Hidrología)
cooking fuel. Natives commonly construct “quincha” houses (partly of clay) with palm roof while Andean settlers prefer wood with corrugated metal roof (Figure 3.6 and 3.7 respectively).

3.3 Upland soils

*Are there variations in the chemical composition of upland soils that are caused by differences in land-cover and land-use?*

To determine if deforestation and land-use change have induced differences in the chemical composition of soils, in particular in terms of nutrients and potentially toxic elements, upland soils (Inceptisols) of two areas were investigated, one in each studied basin (Figure 3.2). Locations for soil sampling were selected from areas with lithology and overburden characteristic to that of the highland jungle. Further, to enable a comparison of soil chemistry between forested areas and areas of agricultural land-uses the sampling locations were restricted to areas bordering intact forests. The selected locations were the surroundings of two small villages, established by colonist farmers in the late 20th century (Figure 3.8 and 3.9). Both areas are featured by a hilly and steep topography (premontane) of redbed lithologies composed by silts interbedded with sandstones and a few limestones (Hermoza et al. 2005). The aerial distance between the two locations is 60 km and the difference in elevation nearly 500 meters.

In the two studied areas soils under five types of land-cover were sampled. Those were primary forests, plots of recently slashed and burnt forest, coffee plantations, pastures and secondary forests (Figure 3.10-3.11). Soils of primary forest (old growth forest, virgin forest; *monte alto*) were sampled to obtain a measure of the magnitude and variation of element concentrations in undisturbed soils (i.e. soil with very little impact from human activities). These data served as a control when investigating for differences in chemical composition of soils under human-induced vegetation. The primary forests were however likely to have been subjected to selective logging but not to slash and burn. Soils of recently swidden fields were sampled to investigate the immediate or short-term effects of clearing and burning of forest. The fields were cleared from forest, in most cases primary, within months prior to sampling. The two agricultural land uses selected for sampling were pastures and coffee plantations. Pasture is one of the most extensive land-uses in the San Martin region and also the most frequently studied elsewhere in the Amazon Basin, which allows for comparisons of results. Pasture of the Brachiaria species was selected because it is regionally the most common (Ramírez 2004). The pastures were grazed by ca. 3 cattle per ha, unfertilized...
cooking fuel. Natives commonly construct "quincha" houses (partly of clay) with palm roof while Andean settlers prefer wood with corrugated metal roof (Figure 3.6 and 3.7 respectively).

3.3 Upland soils

Are there variations in the chemical composition of upland soils that are caused by differences in land-cover and land-use?

To determine if deforestation and land-use change have induced differences in the chemical composition of soils, in particular in terms of nutrients and potentially toxic elements, upland soils (Inceptisols) of two areas were investigated, one in each studied basin (Figure 3.2). Locations for soil sampling were selected from areas with lithology and overburden characteristic to that of the highland jungle. Further, to enable a comparison of soil chemistry between forested areas and areas of agricultural land-uses the sampling locations were restricted to areas bordering intact forests. The selected locations were the surroundings of two small villages, established by colonist farmers in the late 20th century (Figure 3.8 and 3.9). Both areas are featured by a hilly and steep topography (premontane) of redbed lithologies composed by silts interbedded with sandstones and a few limestones (Hermoza et al. 2005). The aerial distance between the two locations is 60 km and the difference in elevation nearly 500 meters.

In the two studied areas soils under five types of land-cover were sampled. Those were primary forests, plots of recently slashed and burnt forest, coffee plantations, pastures and secondary forests (Figure 3.10-3.11). Soils of primary forest (old growth forest, virgin forest; monte alto) were sampled to obtain a measure of the magnitude and variation of element concentrations in undisturbed soils (i.e. soil with very little impact from human activities). These data served as a control when investigating for differences in chemical composition of soils under human-induced vegetation. The primary forests were however likely to have been subjected to selective logging but not to slash and burn. Soils of recently swidden fields were sampled to investigate the immediate or short-term effects of clearing and burning of forest. The fields were cleared from forest, in most cases primary, within months prior to sampling. The two agricultural land uses selected for sampling were pastures and coffee plantations. Pasture is one of the most extensive land-uses in the San Martin region and also the most frequently studied elsewhere in the Amazon Basin, which allows for comparisons of results. Pasture of the Brachiaria species was selected because it is regionally the most common (Ramírez 2004). The pastures were grazed by ca. 3 cattle per ha, unfertilized.
Figure 3.10  Land covers for which differences in soil quality were studied
Figure 3.11 Recently swidden field

Figure 3.12 Sub-basin in upper Saposoa with areas classified as deforested marked with red hatch. Waterbodies and watershed boundaries (white line), water divide between Saposoa and Sisa river basins (black line) and stream water sampling point (black dot) is shown. SPOT image source: (© CNES (2005) distribution Spot Image SA)
but subjected to periodic burning for regeneration. Coffee plantations were studied because they, together with cacao plantations, are regionally becoming increasingly important for livelihood and are considered to be more sustainable than pastures and annual crops (Hartemink 2005). The coffee plantations were shaded (café bajo sombra) and unfertilized. Most sites had been cleared from primary forest for the specific purpose of growing coffee. Soils of secondary forest were studied to investigate how the chemical composition of soil changes when it is left uncultivated (fallow land, purma) and successional (regenerating) vegetation reclaims the land. The secondary forests were dominated by Cetico (Cecropia sp.) and had at the time of sampling already undergone at least one but often several cycles of slash and burn agriculture. The farmer responsible for each plot was accompanying at the selection of the sites and commonly also during the sampling. The areal extent of each site was in general at least 1 ha. Farmers were asked to report on the management history of each field, i.e. year slash-and-burn of primary forest took place and following cultivation periods and burn events ever since (Table 3.1). To enable an analysis of chemical composition between soils that had been used for the same purpose but for different durations since the last burn or since it was abandoned, coffee plantations, pastures and secondary forests of varying age were sampled. Both sampled locations were populated relatively recently and thus the time the soils had been under use was relatively short. The sites that had been part of the slash-and-burn cycle for the longest time were first cleared some 40 years ago in Sisa and some 20 years ago in Saposoa. The current coffee plantations were between 3 and 11 years old, pastures between 1 and 11 years and secondary forests between 3 and 17 years.

In total 80 sites were sampled at a minimum of two depths: 0-10 cm (surface soil or "topsoil") and 20-30 cm ("sub soil"). At four sites of each land cover class profiles of six depths were sampled (in Saposoa). In addition to the soil samples one ash sample was collected from the surface of swidden fields. A vertical soil profile for each studied land-cover is shown in Figure 3.13. Differences in elevation and slope between the soil sites were inevitable due to the hilly character of the landscape and also since sampling was restricted to fields governed by the group of cooperating farmers. However, for each of the two locations, there were no significant differences in these characteristics between soil sites of the five land cover classes (p >0.01). Median elevation of the sampling sites was 1202 masl in Sisa and 730 masl while median slope was 33% and 24%, respectively.

The soil samples were sent to a nearby laboratory for sample preparation (drying, homogenization and discarding of the >2mm fraction) and conventional analysis of soil chemistry and texture (Table 3.4). Samples were sieved to include only particles smaller than 0.1 mm. The amount of this finer fraction was similar between soils of the different land-covers (p >0.05). Soil
but subjected to periodic burning for regeneration. Coffee plantations were studied because they, together with cacao plantations, are regionally becoming increasingly important for livelihood and are considered to be more sustainable than pastures and annual crops (Hartemink 2005). The coffee plantations were shaded (café bajo sombra) and unfertilized. Most sites had been cleared from primary forest for the specific purpose of growing coffee. Soils of secondary forest were studied to investigate how the chemical composition of soil changes when it is left uncultivated (fallow land, purma) and successional (regenerating) vegetation reclaims the land. The secondary forests were dominated by Cetico (Cecropia sp.) and had at the time of sampling already undergone at least one but often several cycles of slash and burn agriculture.

The farmer responsible for each plot was accompanying at the selection of the sites and commonly also during the sampling. The areal extent of each site was in general at least 1 ha. Farmers were asked to report on the management history of each field, i.e. year slash-and-burn of primary forest took place and following cultivation periods and burn events ever since (Table 3.1). To enable an analysis of chemical composition between soils that had been used for the same purpose but for different durations since the last burn or since it was abandoned, coffee plantations, pastures and secondary forests of varying age were sampled. Both sampled locations were populated relatively recently and thus the time the soils had been under use was relatively short. The sites that had been part of the slash-and burn cycle for the longest time were first cleared some 40 years ago in Sisa and some 20 years ago in Saposoa. The current coffee plantations were between 3 and 11 years old, pastures between 1 and 11 years and secondary forests between 3 and 17 years.

In total 80 sites were sampled at a minimum of two depths: 0-10 cm (surface soil or “topsoil”) and 20-30 cm (“subsoil”). At four sites of each land cover class profiles of six depths were sampled (in Saposoa). In addition to the soil samples one ash sample was collected from the surface of swidden fields. A vertical soil profile for each studied land-cover is shown in Figure 3.13. Differences in elevation and slope between the soil sites were inevitable due to the hilly character of the landscape and also since sampling was restricted to fields governed by the group of cooperating farmers. However, for each of the two locations, there were no significant differences in these characteristics between soil sites of the five land cover classes (p >0.01). Median elevation of the sampling sites was 1202 masl in Sisa and 730 masl in Saposoa while median slope was 33 % and 24 %, respectively.

The soil samples were sent to a nearby laboratory for sample preparation (drying, homogenization and discarding of the >2mm fraction) and conventional analysis of soil chemistry and texture (Table 3.4). Samples were sieved to include only particles smaller than 0.1 mm. The amount of this finer fraction was similar between soils of the different land-covers (p >0.05). Soil
samples of the <0.1 mm fraction and the ash samples were sent to an international laboratory for multi-element analysis (Table 3.4). Analysis on soil were carried out with three different leaches to extract near total concentrations, elements associated with carbonates\(^5\), elements bound to humic and fulvic compounds\(^5\), and plant available (exchangeable) concentrations. Ash was analysed with only the strongest leach.

Univariate statistical methods were applied to investigate for differences in soil chemistry between selected sub-groups based on land cover class, depth, location and land cover age (Table 3.2). The analyses were carried out for Sisa and Saposoa data combined as well as separately for each area. The relative control on soil nutrients from land-cover type compared to a number of natural factors (texture, field slope and predominant slope direction) was investigated applying multivariate statistics. The modelled independent (n=11) and dependent variables (n=20) are presented in Table 3.3.

### 3.4 Surface water and sub-basin physical properties

*Is the degree of deforestation and associated agricultural land-use reflected in the chemistry of stream-water?*

To determine if there are differences in stream water quality that can be associated with the areal extents of cleared forest in their respective drainage areas tributaries to the main river of both studied river basins were sampled. In total, water was collected from 27 and 21 independent sub-basin streams in Sisa and Saposoa, respectively (Figure 3.2 and 3.14). These are headwater streams, i.e. of low order (Strahler 1952). In the southern parts of the river basins the climate is seasonally dry and most of the streams are seasonal (intermittent or ephemeral). Thus, not all mapped watercourses were water bearing at the time of sampling. In the northern parts sampling was limited by the rough landscape and the lack of roads or their extremely poor condition (Figure 3.5). The most remote streams were reached by several hours of walking from the nearest road. In addition to the sub-basin sampling the Sisa and Saposoa rivers were sampled at four different sites along their stretches (Figure 3.2 and 3.15 and 3.16). This was carried out once in Sisa and in Saposoa at five different months to investigate how the chemical composition varies between high and low flow. Further, to investigate impacts on water chemistry from deforestation along one of the sub-basin streams a tributary to the Saposoa river was sampled at six sites along its stretch and at two occasions...
samples of the <0.1 mm fraction and the ash samples were sent to an international laboratory for multi-element analysis (Table 3.4). Analysis on soil were carried out with three different leaches to extract near total concentrations, elements associated with carbonates, elements bound to humic and fulvic compounds, and plant available (exchangeable) concentrations. Ash was analysed with only the strongest leach.

Univariate statistical methods were applied to investigate for differences in soil chemistry between selected sub-groups based on land cover class, depth, location and land cover age (Table 3.2). The analyses were carried out for Sisa and Saposoa data combined as well as separately for each area. The relative control on soil nutrients from land-cover type compared to a number of natural factors (texture, field slope and predominant slope direction) was investigated applying multivariate statistics. The modelled independent (n=11) and dependent variables (n=20) are presented in Table 3.3.

3.4 Surface water and sub-basin physical properties

Is the degree of deforestation and associated agricultural land-use reflected in the chemistry of stream-water?

To determine if there are differences in stream water quality that can be associated with the areal extents of cleared forest in their respective drainage areas, tributaries to the main river of both studied river basins were sampled. In total, water was collected from 27 and 21 independent sub-basin streams in Sisa and Saposoa, respectively (Figure 3.2 and 3.14). These are headwater streams, i.e. of low order (Strahler 1952). In the southern parts of the river basins the climate is seasonally dry and most of the streams are seasonal (intermittent or ephemeral). Thus, not all mapped watercourses were water-bearing at the time of sampling. In the northern parts sampling was limited by the rough landscape and the lack of roads or their extremely poor condition (Figure 3.5). The most remote streams were reached by several hours of walking from the nearest road. In addition to the sub-basin sampling the Sisa and Saposoa rivers were sampled at four different sites along their stretches (Figure 3.2 and 3.15 and 3.16) This was carried out once in Sisa and in Saposoa at five different months to investigate how the chemical composition varies between high and low flow. Further, to investigate impacts on water chemistry from deforestation along one of the sub-basin streams a tributary to the Saposoa river was sampled at six sites along its stretch and at two occasions.
Figure 3.15  Sisa river valley (top) and Sisa river near Sisa town (bottom).
Figure 3.16 Saposo river valley (top) and Saposo river near Saposo town (bottom).
This was carried out two years after the main sampling campaign. Water samples were prepared in situ at each site, directly following collection of the water and according to procedures corresponding to the destined analysis (e.g. filtration and/or conservation with acid). In total 6 sub-samples were prepared at each sampled site. A standard chemical analysis and an analysis of nutrient content were carried out at two different Peruvian laboratories while multi-element analysis and analysis for dissolved organic carbon were performed on filtered (<0.45 μm) samples by two different international laboratories. Refer to Table 3.4 for more details on the analysis.

At each sampling site the velocity of the water was measured with a float (average of five repetitions per stream) and where possible also with a flow meter (five measuring points along one transect per stream). Cross-sectional area was calculated from measured width and the average of five depths across each of the three transects. Refer to Figure 3.17 for illustrations on the velocity measurements and a few other moments from sampling. Discharge was calculated to enable a comparison between chemical data from different sampling events and to enable calculations of exported amounts, e.g. in the case of identification of important translocation of potentially toxic elements.

The land area contributing to discharge at each sampled site and its physical characteristics were delineated in ArcMap applying the hydrological modeling extension TauDEM 3.1 (David Tarboton, Utah State University, USA) and a digital elevation model (DEM) of 90 m resolution. The obtained sub-basin geomorphological features were area, elevation range, average elevation and average slope. The areal extents of different geological units were calculated for each sub-basin based on their derived extents and a digitalized lithological map of scale 1:250 000 (Castro, 2004).

A classification of land cover was carried out applying the ArcView extension Image Analyst, using chiefly SPOT5 images of 10 meter spatial resolution and from the same year as when the water sampling was carried out (© CNES (2005) distribution Spot Image SA; Figure 3.12). A Landsat image (TM 1999) was used when complementary information was required, e.g. where cloud cover masked the land cover in the available SPOT images. In 2005 a SPOT5 satellite was programmed to retrieve further information on the upper parts of the Sisa basin, however, this was unsuccessful due to persistent cloud cover. Unsupervised and supervised classifications were performed individually for each sub-catchment and the results were manually corrected. Land cover was divided into two classes, forested and deforested. The mapped land classified as forested included forest that may have been exposed to selective logging and may also include areas of coffee plantations under tree cover since these were spectrally similar to primary forest.
This was carried out two years after the main sampling campaign.

Water samples were prepared in situ at each site, directly following collection of the water and according to procedures corresponding to the destined analysis (e.g. filtration and/or conservation with acid). In total 6 sub-samples were prepared at each sampled site. A standard chemical analysis and an analysis of nutrient content were carried out at two different Peruvian laboratories while multi-element analysis and analysis for dissolved organic carbon were performed on filtered (<0.45 μm) samples by two different international laboratories. Refer to Table 3.4 for more details on the analysis.

At each sampling site the velocity of the water was measured with a float (average of five repetitions per stream) and where possible also with a flow meter (five measuring points along one transect per stream). Cross-sectional area was calculated from measured width and the average of five depths across each of the three transects. Refer to Figure 3.17 for illustrations on the velocity measurements and a few other moments from sampling. Discharge was calculated to enable a comparison between chemical data from different sampling events and to enable calculations of exported amounts, e.g. in the case of identification of important translocation of potentially toxic elements.

The land area contributing to discharge at each sampled site and its physical characteristics were delineated in ArcMap applying the hydrological modeling extension TauDEM 3.1 (David Tarboton, Utah State University, USA) and a digital elevation model (DEM) of 90 m resolution. The obtained sub-basin geomorphological features were area, elevation range, average elevation and average slope. The areal extents of different geological units were calculated for each sub-basin based on their derived extents and a digitalized lithological map of scale 1:250 000 (Castro, 2004).

A classification of land cover was carried out applying the ArcView extension Image Analyst, using chiefly SPOT5 images of 10 meter spatial resolution and from the same year as when the water sampling was carried out (© CNES (2005) distribution Spot Image SA; Figure 3.12). A Landsat image (TM 1999) was used when complementary information was required, e.g. where cloud cover masked the land cover in the available SPOT images. In 2005 a SPOT5 satellite was programmed to retrieve further information on the upper parts of the Sisa basin, however, this was unsuccessful due to persistent cloud cover. Unsupervised and supervised classifications were performed individually for each sub-catchment and the results were manually corrected. Land cover was divided into two classes, forested and deforested. The mapped land classified as forested included forest that may have been exposed to selective logging and may also include areas of coffee plantations under tree cover since these were spectrally similar to primary forest. The mapped land classified as
deforested included a wide range of land uses such as swidden fields, crops, pastures and regenerating vegetation that had not reached the structure and composition of a mature forest. The areal extents of forested and deforested land were calculated in ArcMap for each sub-basin based on their derived extents and the produced map of land cover. In both basins, the studied sub-basins from which water samples were collected exhibited a large variation regarding areal extent of intact forest, from nearly pristine to highly exploited (Figure 3.2 and 4.3). The range was 7-91 % for Sisa and 15-99 % in Saposoa and median for the total dataset was 40 %.

Univariate statistical methods were applied to investigate for differences in water chemistry between the two river basins and between sub-basins affected to different degrees by deforestation (>50% and <50%; Table 3.2). The influence from the degree of forest cover and the other physical characteristics derived for the sub-basins (n=15) on the chemical variables (n=32) measured in stream waters were investigated with multivariate statistics (Table 3.3). For a selection of chemical variables multiple linear regressions were carried out to distinguish between the relative controls from the two most important physical variables.

3.5 Floodplain sediments

*Have deforestation and agricultural land-use caused an increased translocation of elements from upland soils to downstream areas?*

Geochemical changes in the upstream landscape should be reflected in that of its corresponding floodplain sediments (De Vos et al. 2006; Kalliola et al. 1993). In addition, few samples of floodplain sediments are needed to represent large river basins and can thus replace a larger number of soil samples (Edén and Björklund 1994). The position of floodplain sediments in a natural setting with surrounding soil and bedrock are illustrated in Figure 3.18. The alluvial sediments are formed when river discharge exceeds river channel capacity and the floodplain floor is temporally inundated. Material from upstream sources suspended in the water is deposited on the floodplain when water levels ultimately declines. This process commonly produce near horizontal strata on the floodplain that serve as a geochemical archive with sediments deposited successively longer back in time with increasing depth (Edén and Björklund 1994). Apart from fluvial deposition, inputs of chemical elements can occur through airborne deposition, in-situ vegetation and land management.

Alluvial sediments were sampled in both studied basins. Geomorphologically these floodplains are part of the Andean sedimentation valley and are composed of deep layers of semi-consolidated and unconsolidated gravel,
Deforestation included a wide range of land uses such as swidden fields, crops, pastures and regenerating vegetation that had not reached the structure and composition of a mature forest. The areal extents of forested and deforested land were calculated in ArcMap for each sub-basin based on their derived extents and the produced map of land cover. In both basins, the studied sub-basins from which water samples were collected exhibited a large variation regarding areal extent of intact forest, from nearly pristine to highly exploited (Figure 3.2 and 4.3). The range was 7-91% for Sisa and 15-99% in Saposoa and median for the total dataset was 40%.

Univariate statistical methods were applied to investigate for differences in water chemistry between the two river basins and between sub-basins affected to different degrees by deforestation (>50% and <50%; Table 3.2). The influence from the degree of forest cover and the other physical characteristics derived for the sub-basins (n=15) on the chemical variables (n=32) measured in stream waters were investigated with multivariate statistics (Table 3.3). For a selection of chemical variables multiple linear regressions were carried out to distinguish between the relative controls from the two most important physical variables.

3.5 Floodplain sediments

Have deforestation and agricultural land-use caused an increased translocation of elements from upland soils to downstream areas?

Geochemical changes in the upstream landscape should be reflected in that of its corresponding floodplain sediments (De Vos et al. 2006; Kalliola et al. 1993). In addition, few samples of floodplain sediments are needed to represent large river basins and can thus replace a larger number of soil samples (Edén and Björklund 1994). The position of floodplain sediments in a natural setting with surrounding soil and bedrock are illustrated in Figure 3.18. The alluvial sediments are formed when river discharge exceeds river channel capacity and the floodplain floor is temporally inundated. Material from upstream sources suspended in the water is deposited on the floodplain when water levels ultimately declines. This process commonly produce near horizontal strata on the floodplain that serve as a geochemical archive with sediments deposited successively longer back in time with increasing depth (Edén and Björklund 1994). Apart from fluvial deposition, inputs of chemical elements can occur through airborne deposition, in-situ vegetation and land management.

Alluvial sediments were sampled in both studied basins. Geomorphologically these floodplains are part of the Andean sedimentation valley and are composed of deep layers of semi-consolidated and unconsolidated gravel, sand, silt and clay deposited during late Pleistocene and Holocene (Castro, 2004). Several times each year high-intensity or persistent rainfall events cause flooding which may last for days and water levels may reach about 1 m above the floodplain surface (interview data). Waters covering the floodplains may contain several thousands of mg/L of suspended material (this study; unpublished data Nagel 2005). Flooding may last up to several hours and in depressions several days. When water has retreated within the river channel, infiltrated or evaporated it has left deposits of fresh material ranging from a few centimetres to several decimetres in thickness (field observation and interview data). Wide laminations of several cm to dm thickness in the sediments confirm that large amounts of material have been deposited following floods.

Sampling sites were selected as close to the outlet of the two river basins as possible while avoiding the zone that may be influenced by the Huallaga river at floods (Figure 3.2). In Saposoa a duplicate profile was sampled to obtain information on variability over small spatial scales. To obtain a regional reference samples were also collected from an alluvial island in the Huallaga river (Figure 3.2), also subjected to flooding. Refer to Figure 3.19 and 3.21 for illustrations of high and low water stage at the sampling sites in Sisa and Huallaga respectively. All three sites were exposed to active erosion (i.e. cut banks) and located on the margins of their respective river channel (Figure 3.19 to 3.21). The near vertical banks of between 2 and over 4 m were sampled starting from the base and working upwards. Composite material was
sampled for intervals of maximum 10 cm. The material was unconsolidated and of sandy to sandy loamy texture. The land owner of each sampled location was asked about the year when burning of the primary forest had taken place and land use ever since (Table 3.1). The sites in Sisa and Saposoa had similar land management histories, and the sampled locations had been slashed and burnt twice. Primary forest was covering the sites until 1963 in Sisa and 1985 in Saposoa when it was slashed and burnt to obtain agricultural land. After some time the land was left for forest to regenerate but was slashed and burnt again in 1978 in Sisa and in 1997 in Saposoa, to create pasture land. At the time of sampling the Saposoa site was still a grazing area while Sisa was on the margin of rice fields. The location in Huallaga had been burnt once (in 2004) to open up land for cultivation of plantain.

A layer of combustion residues was identified in each of the sampled sediment profiles except in Sisa where there were two. In one of the Saposoa profiles at ca. 1 m depth and in the Huallaga profile at ca. 0.1 m depth, the layers were continuous and horizontal and composed by fine ash and a range of sizes of charcoal fragments (Figure 3.20). In the other two profiles (at ca. 1 m depth) the layers were more uneven and mainly consisted of small and dispersed charcoal fragments. The deeper of the two layers in the Sisa profile (at ca. 2 m depth) was more fragmented and disintegrated than the upper one. Two years after the first sampling event the sites were revisited. Since the river banks are highly unstable all sites had been intensely eroded, several meters in a horizontal direction (over 10 m at the Saposoa location). On the newly exposed surfaces samples were taken from the combustion layers and the layers immediately above and below them. The combustion layers were located at the same depth as in the original profiles. The Huallaga site had been eroded to such a degree that it was not possible to locate the ash layer. Local farmers estimated that 20 % of the island had disappeared in connection to a flood in 2006 and hence no additional sampling was undertaken there.

The sediment samples were sent to a nearby laboratory for sample preparation (drying, homogenization and discarding of the >2mm fraction), a few chemical analyses and grain size distribution. Samples were sieved to include only particles smaller than 0.1 mm. The amount of this finer fraction was similar, ca. 30 %, in sediments of Sisa and Saposoa, while it constituted more than half of the amount of material in the Huallaga sediments. Samples of the fine fraction and the ash samples were sent to an international laboratory for multi-element analysis. Analyses on sediment were carried out with two different leaches to extract near total concentrations (all samples) and elements
sampled for intervals of maximum 10 cm. The material was unconsolidated and of sandy to sandy loamy texture. The land owner of each sampled location was asked about the year when burning of the primary forest had taken place and land use ever since (Table 3.1). The sites in Sisa and Saposoa had similar land management histories, and the sampled locations had been slashed and burnt twice. Primary forest was covering the sites until 1963 in Sisa and 1985 in Saposoa when it was slashed and burnt to obtain agricultural land. After some time the land was left for forest to regenerate but was slashed and burnt again in 1978 in Sisa and in 1997 in Saposoa, to create pasture land. At the time of sampling the Saposoa site was still a grazing area while Sisa was on the margin of rice fields. The location in Huallaga had been burnt once (in 2004) to open up land for cultivation of plantain.

A layer of combustion residues was identified in each of the sampled sediment profiles except in Sisa where there were two. In one of the Saposoa profiles at ca. 1 m depth and in the Huallaga profile at ca. 0.1 m depth, the layers were continuous and horizontal and composed by fine ash and a range of sizes of charcoal fragments (Figure 3.20). In the other two profiles (at ca. 1 m depth) the layers were more uneven and mainly consisted of small and dispersed charcoal fragments. The deeper of the two layers in the Sisa profile (at ca. 2 m depth) was more fragmented and disintegrated than the upper one. Two years after the first sampling event the sites were revisited. Since the river banks are highly unstable all sites had been intensely eroded, several meters in a horizontal direction (over 10 m at the Saposoa location). On the newly exposed surfaces samples were taken from the combustion layers and the layers immediately above and below them. The combustion layers were located at the same depth as in the original profiles. The Huallaga site had been eroded to such a degree that it was not possible to locate the ash layer. Local farmers estimated that 20% of the island had disappeared in connection to a flood in 2006 and hence no additional sampling was undertaken there.

The sediment samples were sent to a nearby laboratory for sample preparation (drying, homogenization and discarding of the >2mm fraction), a few chemical analyses and grain size distribution. Samples were sieved to include only particles smaller than 0.1 mm. The amount of this finer fraction was similar, ca. 30%, in sediments of Sisa and Saposoa, while it constituted more than half of the amount of material in the Huallaga sediments. Samples of the fine fraction and the ash samples were sent to an international laboratory for multi-element analysis. Analyses on sediment were carried out with two different leaches to extract near total concentrations (all samples) and elements

Figure 3.19   Floodplain sampling location with over 4 m high river banks in Sisa basin. Top: river bank prior to sampling (arrow show sampling site). Middle: Sisa river at low water stage. (Same site as top photo but facing upriver.) Bottom: Sisa river at high water stage.
Figure 3.20  Floodplain sampling location with ca 2 m high river banks in Saposoa basin (arrow show sampling site). Left: Saposoa sediment profile (ash layer at little over 1 m from surface) Middle right: sediment site setting (Google Earth 20051124) Bottom right: close up on ash layer
Figure 3.21  Top: alluvial island in the Huallaga basin where sampling was carried out (Google Earth, 20051124) Middle left: sampling site at low water stage Bottom left: sampling site at high water stage Right: sampled sediment profile
Atmospheric fallout of 137Cs is bound to clay particles and is transported together with soil and sediments. It can therefore be used to obtain time markers in sediment profiles and to calculate average sedimentation rates over the last ca. 50 years (Walling & He 1997). Also in environments with high and variable sedimentation rates, such as that of the studied basins, radiometric dating of sediments has proven feasible (El-Daoushy & Eriksson 1998). Thus, material from the Sisa and Saposoa profiles was run for determination of 137Cs concentrations at an international laboratory. Due to anticipated low concentrations large sample amounts were used (>50g) and each sample was analysed for up to 120 h. The Huallaga profile was not analysed for 137Cs since a chronostratigraphic sequence of layers was not expected due to the character of the sediments (exposed to reworking and resettling from river actions).

3.6 People

In what ways and to what degrees have deforestation and agricultural activities affected the natural environment and rural livelihoods according to small-scale farmers?

Interviews were carried out with smallholder farmers to obtain an overview of the environmental effects of deforestation and land-use change in the two studied basins and to learn how this has affected local livelihoods (Figure 3.22). Their perceptions and attitudes towards the environment were investigated through structured interviews that took place in-situ, face-to-face, in their homes. In total, 51 individual farmers from six villages, three in each studied river basin, participated in the study (Figure 3.2; Table 3.1). The selection of villages and respondents was made to meet the requirements of the study which involved farmer origin, gender and age. Respondents of ages distributed over the range for active farmers were included. The interviews were equally divided between men and women as well as between native and colonist farmers. All native farmers were mestizos (i.e. people with mixed descent, both indigenous and European). Indigenous peoples, such as the Kechwa-Lamistas whose livelihoods and worldviews are discussed in Arévalo et al. (1999) and Rengifo et al. (1993), were not included in this study.

The interviews were composed by a set of questions of both quantitative and qualitative character where farmers frequently were encouraged to motivate and explain their replies. A combination of quantitative and qualitative data has proven beneficial in several previous studies (Lindström et al. 2006;
bound to humic and fulvic compounds (a selection of samples). Ash was analysed with the strongest leach only. A list of the chemical variables determined in the sediment and ash samples can be found in Table 3.4.

Atmospheric fallout of $^{137}$Cs is bond to clay particles and is transported together with soil and sediments. It can therefore be used to obtain time markers in sediment profiles and to calculate average sedimentation rates over the last ca. 50 years (Walling & He 1997). Also in environments with high and variable sedimentation rates, such as that of the studied basins, radiometric dating of sediments has proven feasible (El-Daoushy & Eriksson 1998). Thus, material from the Sisa and Saposoa profiles was run for determination of $^{137}$Cs concentrations at an international laboratory. Due to anticipated low concentrations large sample amounts were used (>50g) and each sample was analysed for up to 120 h. The Huallaga profile was not analysed for $^{137}$Cs since a chronostratigraphic sequence of layers was not expected due to the character of the sediments (exposed to reworking and resettling from river actions).

### 3.6 People

*In what ways and to what degrees have deforestation and agricultural activities affected the natural environment and rural livelihoods according to small-scale farmers?*

Interviews were carried out with smallholder farmers to obtain an overview of the environmental effects of deforestation and land-use change in the two studied basins and to learn how this has affected local livelihoods (Figure 3.22). Their perceptions and attitudes towards the environment were investigated through structured interviews that took place in-situ, face-to-face, in their homes. In total, 51 individual farmers from six villages, three in each studied river basin, participated in the study (Figure 3.2; Table 3.1). The selection of villages and respondents was made to meet the requirements of the study which involved farmer origin, gender and age. Respondents of ages distributed over the range for active farmers were included. The interviews were equally divided between men and women as well as between native and colonist farmers. All native farmers were mestizos (i.e. people with mixed descent, both indigenous and European). Indigenous peoples, such as the Kechwa-Lamistas whose livelihoods and worldviews are discussed in Arévalo et al. (1999) and Rengifo et al. (1993), were not included in this study.

The interviews were composed by a set of questions of both quantitative and qualitative character where farmers frequently were encouraged to motivate and explain their replies. A combination of quantitative and qualitative data has proven beneficial in several previous studies (Lindström et al. 2006;
Johansson & Henningsson 2011). The following themes were included in the interviews:

- socio-economic characteristics and livelihood (e.g. age, education level, marital status, religious beliefs, occupation, land holdings and income)
- reason for migration (only posed to colonists)
- use and management of natural resources
- attitudes towards slash-and-burn, fertilizers, pesticides, irrigation etc
- attitudes towards the natural environment
- importance of natural resources in general and compared to factors of social welfare such as security, health and education
- nature and magnitude of environmental changes
- preoccupation towards environmental change
- causes of environmental change
- attitudes towards population growth and colonization
- responsibility for environmental protection and management divided between different stake holders including farmers, governmental and non governmental organizations and authorities
- possible mitigation measures for an improved state of the environment and capability or willingness of farmers to cooperate in their implementation
- outlook for the future with respect to livelihood and sustainable development

The interviews were carried out in Spanish - the first language of all respondents. Local words and simple expressions were used rather than technical terminology and an informal tone was used throughout the interviews. The interviews were divided into two sessions of approximately two hours each and in most cases there was also a third, complementary, visit to work out uncertainties and add missing information.

The results presented in this thesis are mainly based on one of the themes listed above: nature and magnitude of environmental changes. Focus was on forest, soil/land and surface water. In detail, the farmers were asked if a certain issue related to the environment had changed over time and was given the option to disagree or agree. In the case of agreement the farmer was asked to describe the nature of the change and to estimate when the change had become notable to them. To identify the relative importance between the perceived changes the farmers were asked to rate its magnitude. In general, quantitative data were obtained applying a Likert-type rating scale with the following levels: 1= small/little, 2= regular, 3= large/much, 4= very large/very much, and 0= disagree (Likert 1932). The answer “do not know” was not rated. The scoring process was facilitated by using cards illustrating each level of the scale, a simplified version of the Q-sort method (Kerlinger 1964).
The following themes were included in the interviews:

• socio-economic characteristics and livelihood (e.g. age, education level, marital status, religious beliefs, occupation, land holdings and income)
• reason for migration (only posed to colonists)
• use and management of natural resources
• attitudes towards slash-and-burn, fertilizers, pesticides, irrigation etc
• attitudes towards the natural environment
• importance of natural resources in general and compared to factors of social welfare such as security, health and education
• nature and magnitude of environmental changes
• preoccupation towards environmental change
• causes of environmental change
• attitudes towards population growth and colonization
• responsibility for environmental protection and management divided between different stakeholders including farmers, governmental and non-governmental organizations and authorities
• possible mitigation measures for an improved state of the environment and capability or willingness of farmers to cooperate in their implementation
• outlook for the future with respect to livelihood and sustainable development

The interviews were carried out in Spanish - the first language of all respondents. Local words and simple expressions were used rather than technical terminology and an informal tone was used throughout the interviews. The interviews were divided into two sessions of approximately two hours each and in most cases there was also a third, complementary, visit to work out uncertainties and add missing information.

The results presented in this thesis are mainly based on one of the themes listed above: nature and magnitude of environmental changes. Focus was on forest, soil/land and surface water. In detail, the farmers were asked if a certain issue related to the environment had changed over time and was given the option to disagree or agree. In the case of agreement the farmer was asked to describe the nature of the change and to estimate when the change had become notable to them. To identify the relative importance between the perceived changes the farmers were asked to rate its magnitude. In general, quantitative data were obtained applying a Likert-type rating scale with the following levels: 1= small/little, 2= regular, 3= large/much, 4= very large/very much, and 0= disagree (Likert 1932). The answer "do not know" was not rated. The scoring process was facilitated by using cards illustrating each level of the scale, a simplified version of the Q-sort method (Kerlinger 1964).
These were displayed in front of the respondents throughout the interviews (Figure 3.23).

The responses were continuously registered by the interviewer on a questionnaire and also recorded with a Dictaphone. The recorded material was transcribed manually, word-for-word. Quantitative and qualitative data were extracted from the transcribed texts. The quantitative data was used to calculate percentage of responses and descriptive statistics. The qualitative data was systematically processed to identify keywords or key-expressions common to several individuals. These were structured and coded to enable the calculation of their occurrence as percentage of total responses (Parker 2005). Differences in perceptions and views between native and colonist farmers as well as between men and women were investigated with univariate statistics (Table 3.2).

Figure 3.24 A development plan for one of the studied villages (Figure 3.7) including tourist attractions and environmental enhancements. Elaborated by one of the local farmers.
4. FINDINGS

4.1 River basin chemical characteristics

The sampled environment is part of the Subandean Cordillera, an easily disintegrated belt, in parts highly enriched in carbonate and evaporitic deposits. In line with previously published results (Stallard & Edmond 1983) this lithology was found to exert a strong control on the chemical composition of stream water. Sampled streams were rich in both suspended and dissolved matter, were alkaline (median pH 8.2) and overall dominated by Ca-HCO$_3$. The large variation in concentration of total dissolved salts (TZ) between streams of different sub-basins is likely caused by a heterogeneous distribution of carbonates and evaporitic deposits of both halite and gypsum/anhydrite. The concentrations of major elements as compared to global means and those of other Amazon settings were high (Table 4.1). The relative amount of HCO$_3$ compared to other anions was on an average 74 % (except for streams draining massive evaporites) and the correlation between TZ and Ca, Mg and HCO$_3$ was strong ($r = 0.9$). Thus, high loads of dissolved salts were accounted for by carbonate dissolution alone.

The sediment profiles near the outlets of the basins had high pH (median 8.1) and high concentrations of Ca and K when compared both to upstream soils, the regional Huallaga profile, and to sediments originating in other areas of the Peruvian jungle (Kalliola et al., 1993; personal communication with Kalliola- data from 1993). The upland soils were additionally lower in Mg and both the soils and the Huallaga profile were higher in OM and a few trace elements including Hg.

Sampled Inceptisols of premontane areas exhibited a more heterogeneous chemical composition between the two basins than the stream waters and floodplain sediments. While all surface soils in Sisa were eutric (median base saturation (BS) 100 %) there was a great spread in the soils of Saposoa with soils ranging from nutrient poor with high levels of exchangeable Al and acidic topsoil to nutrient rich (median BS 57 %; Figure 4.1). Overall, the sampled soils were found to be relatively fertile (e.g. higher CECe, Ca and P) when
compared to soils of the Amazon lowland (Oxisols and Ultisols; McGrath et al. 2001) in particular, but also to other soils of San Martin (Inceptisols and Entisols; Escobedo 2004; Figure 4.2). Several nutrients were however frequently available in concentrations (absolute or relative) that may limit soil fertility, both in soils of low and high BS. Those were K, NO₃, Mg (Sisa), Cu, Fe, and Zn (Saposoa).

Trace element concentrations were in general low in all sampled media.
compared to soils of the Amazon lowland (Oxisols and Ultisols; McGrath et al. 2001) in particular, but also to other soils of San Martin (Inceptisols and Entisols; Escobedo 2004; Figure 4.2). Several nutrients were however frequently available in concentrations (absolute or relative) that may limit soil fertility, both in soils of low and high BS. Those were K, NO₃, Mg (Sisa), Cu, Fe, and Zn (Saposoa).

Trace element concentrations were in general low in all sampled media.

---

**Figure 4.1** Base saturation (%) for soils of different land covers in Sisa (left) and Saposoa (right) surface soils. Means (+) and medians (|) are marked.

**Figure 4.2** Indicators of chemical fertility in Entisols and Inceptisol soils of Sisa, Saposoa and San Martin, and Ultisols and Oxisols of the Amazon lowland. Data source: this study, Escobedo 2004 and McGrath 2001. Means (+) and medians (|) are marked.
4.2 Environmental changes

4.2.1 Migration of people
Currently a couple of new families arrive each month to settle in the studied villages. While the range in time since arrival of the migrant settlers of this study was large (2-36 years), the majority arrived to the highland jungle around the start of the second millennia. Their origin was foremost the high Andes (77 %) but also the coast (15 %). The primary reason for such a large change in life was the need to reach subsistence which was reported inadequate in the native regions due to lack of land (81 %) and low yields caused by deficiencies in rainfall (19 %).

4.2.2 Forest cover
A major decline in forest cover over time and a current great deficiency of forest was reported by the inhabitants of the two river basins. A little more than one third of the farmers were in possession of primary forest (monte alto). Only farmers living in the upper parts of the river basins claimed there is still primary forest available for purchase. Several farmers in the lower parts of the basins, both native and colonists, informed that they did not know much about primary forests. The remarks of one of the colonist farmers serve as an example: “we have not heard of any virgin forest around here, they say you can find some in the upper parts of Saposoa,”. The farmers’ perception on forest availability is in line with the land cover analysis based on remote sensing (Figure 3.2).

The derived information on geomorphology of watersheds of Sisa and Saposoa river basins combined with data on forest-cover show that in both river basins the degree of exploitation increases with decreasing altitude (Figure 4.3). For a given watershed average elevation a smaller part of the total

---

Question posed was “Why did you decide to move to the highland jungle”?
area was covered by forest in sub-basins of Sisa compared to Saposoa which is in line with the overall greater extent of deforestation in Sisa (70 % vs. 30 %). Both within and between the two river basins the difference in forest cover for a given watershed average elevation was larger at higher elevations compared to lower. Overall, sub-basins with less than 40 % of their area covered by forest all had average elevations of <900 m and sub-basins with more than 80 % forest all had average elevations of >700 m.

### 4.2.3 Soil quality

The inhabitants of Sisa and Saposoa river basins informed that soil fertility has decreased to a moderate degree over time (Table 4.2). Current soil quality was perceived to be poor to moderate. Lack of soil nutrients, a major decline in fallow duration and lack of rainfall were appointed as main causes to limited soil fertility: "the soil,„is impoverished now„,„they are tired„,„to me it seems it is because too much planting„,„so many years it has been used now, the organic material is impoverished,„and the lack of rain„,„it no longer rains constantly„,„little rain„,„it almost does not produce any more„,our products do not grow, everything depends on the rain and the care" (Table 4.3). In the study on soil chemistry however, soils were found to be naturally variable in terms of nutrients (poor to rich) and although soils frequently were found to be low in one or several nutrients there were no evidence to support that fertility decline is caused by an associated decline in soil nutrient content. In contrast, soils of primary forest were found to be chemically similar to soils of coffee plantations, Brachiaria pastures and secondary forests that in most cases had been cultivated for more than 10 years.
The limited co-variation between land cover and soil chemistry is illustrated in a PCA loadings plot (Figure 4.4) and the absence of distinct clusters for soils of the same land cover class, both within and between the two soil locations is illustrated in a PCA score plot (Figure 4.5). Thus, deforestation and land use is not the factor responsible for the great variation in soil chemistry within the Sapsoa location described in Section 4.1.

While the spread in median concentrations of chemical variables generally were larger in surface soil compared to soil at larger depths (Figure 4.6), the differences were not statistically recognized. The apparent higher K in pasture soils (as also in Sisa) and lower pH in primary forest soils were not statistically significant. The latter is likely the result of one more sampled primary forest site over acid parent material, compared to the other land covers, which was evident when studying the variations with depth for individual sites.

Note: not all farmers made a comment on each theme and opinions shared by less than 10% of the respondents are not shown.

---

52
prior to regeneration. The limited co-variation between land cover and soil chemistry is illustrated in a PCA loadings plot (Figure 4.4) and the absence of distinct clusters for soils of the same land cover class, both within and between the two soil locations is illustrated in a PCA score plot (Figure 4.5). Thus, deforestation and land use is not the factor responsible for the great variation in soil chemistry within the Sapsoa location described in Section 4.1.

While the spread in median concentrations of chemical variables generally were larger in surface soil compared to soil at larger depths (Figure 4.6), the differences were not statistically recognized. The apparent higher K in pasture soils (as also in Sisa) and lower pH in primary forest soils were not statistically significant. The latter is likely the result of one more sampled primary forest site over acid parent material, compared to the other land covers, which was evident when studying the variations with depth for individual sites. Thus, the influence from vegetation and land-use was insignificant (i.e. very small) compared to natural controls, which is also demonstrated by the results from the PLSR2 model that explained 38.5% of the total variance in the chemical variables. The most

Figure 4.4 PCA loadings plot over chemical and physical variables of upland surface soils in Sisa and Sapsoa river basins. Land covers are marked in blue.

Figure 4.5 PCA score plot over the sampled sites of upland surface soils in Sisa (Sis) and Sapsoa (Sap) river basins. Primary forest soil sites are marked in red.
important (first) component of the PLSR2 model was positively correlated to a large number of variables associated with high soil fertility (e.g. N, CECe, Ca, pH, Mg and OM) while negatively correlated to exchangeable acidity. Overall, natural controls, in the following order; soil texture (sand, clay and silt), study location (i.e. Sisa and Saposoa) and slope, were all stronger controls on soil chemical composition than any of the land covers, of which the class of swidden fields was the only one with a significant influence on the model. Variations of the PLSR2 model run with i) pH and DOC and ii) pH, DOC, Fe, Al and Mn, as part of the predictor variables returned similar results as the original model. The best predictor of the soil chemical composition was the relative amount of sand (%). Soil texture was also the most frequently reported fertility indicator according to discussions with the land owners of the sampled sites.

The analysis of differences in soil fertility with age of land covers (pasture, coffee plantations and secondary vegetation) were in line with the results of overall insignificant impact from land-use. There were however a few chemical components that could be associated with time of establishment of a particular land cover but the results were different between the two river basins. In Sisa, exchangeable K was negatively correlated with pasture age (rs=-0.7) while in Saposoa higher median NO3 concentrations were detected in young (≤2 years) pasture soil compared to older (≥5 years), 4.5 ppm and 0.9 ppm, respectively, in surface soil and 5.1 ppm and 1.1 ppm, respectively, in sub soil. In coffee plantations, the K/Mg ratio correlated positively with age (rs=1.0), but only in Saposoa. The lack of consistent or clear relations between land cover age and soil fertility is in agreement with several previous studies (Müller et al., 2004; McGrath et al., 2001; Numata et al., 2007).

An important exception to the lack of differences between soils under different land covers was the nutrient input following slash and burn (swidden fields). This was strongly significant for NO3 and EC (p< 0.001) and a weaker but significant influence was identified for K, P and Fe (p< 0.05). Similar results were returned from univariate statistical calculations (Table 3.2). The vertical distribution of K, NO3 and EC in Saposoa sites is shown in Figure 4.6 (a, b and c). The source of the nutrient enrichment is attributable to input from combustion residues. Ash collected from the recently swidden fields were highly enriched in major nutrients compared to the underlying surface soil, for example, the aqua regia extractable ratios for K and P were 17:1 and 14:1 respectively. The enrichment effects of slash and burn seemed short-lived since it could not be detected in the other agricultural soils that are part of the slash-and-burn cycle. In addition, exchangeable K and NO3 were subjected to

---

Figur 4.6 Vertical distribution of a selection of chemical variables (medians) for which swidden fields were significantly enriched (a–c) and others (d–f) for which there were no statistical differences between soils of the five land cover classes. Location: Saposoa
important (first) component of the PLSR2 model was positively correlated to a large number of variables associated with high soil fertility (e.g. N, CECe, Ca, pH, Mg and OM) while negatively correlated to exchangeable acidity.

Overall, natural controls, in the following order; soil texture (sand, clay and silt), study location (i.e. Sisa and Saposa) and slope, were all stronger controls on soil chemical composition than any of the land covers, of which the class of swidden fields was the only one with a significant influence on the model. Variations of the PLSR2 model run with i) pH and DOC and ii) pH, DOC, Fe, Al and Mn, as part of the predictor variables returned similar results as the original model. The best predictor of the soil chemical composition was the relative amount of sand (%). Soil texture was also the most frequently reported fertility indicator according to discussions with the land owners of the sampled sites.

The analysis of differences in soil fertility with age of land covers (pasture, coffee plantations and secondary vegetation) were in line with the results of overall insignificant impact from land-use. There were however a few chemical components that could be associated with time of establishment of a particular land cover but the results were different between the two river basins. In Sisa, exchangeable K was negatively correlated with pasture age (r_s=-0.7) while in Saposa higher median NO_3 concentrations were detected in young (≤2 years) pasture soil compared to older (≥5 years), 4.5 ppm and 0.9 ppm, respectively, in surface soil and 5.1 ppm and 1.1 ppm, respectively, in sub soil. In coffee plantations, the K/Mg ratio correlated positively with age (r_s=1.0), but only in Saposa. The lack of consistent or clear relations between land cover age and soil fertility is in agreement with several previous studies (Müller et al., 2004; McGrath et al., 2001; Numata et al., 2007).

An important exception to the lack of differences between soils under different land covers was the nutrient input following slash and burn (swidden fields). This was strongly significant for NO_3 and EC (p< 0.001) and a weaker but significant influence was identified for K, P and Fe (p< 0.05). Similar results were returned from univariate statistical calculations (Table 3.2). The vertical distribution of K, NO_3 and EC in Saposa sites is shown in Figure 4.6 (a, b and c). The source of the nutrient enrichment is attributable to input from combustion residues. Ash collected from the recently swidden fields were highly enriched in major nutrients compared to the underlying surface soil, for example, the aqua regia extractable ratios for K and P were 17:1 and 14:1 respectively. The enrichment effects of slash and burn seemed short-lived since it could not be detected in the other agricultural soils that are part of the slash-and-burn cycle. In addition, exchangeable K and NO_3 were subjected to

---

8 The overall explained model variance for these elements was 60 % for EC, 51 % for Fe, 43 % for NO_3, 21 % for K and 10 % for P.
leaching. Both variables were found to be elevated also in subsoil, at 30 cm depth, and NO$_3$ in Saposoa down to at least 60 cm depth (Figure 4.6, a and b). An initial increase in nutrient concentrations after burning, caused by ash input, and subsequent leaching is in agreement with the majority of previously published results (Klinge et al., 2004; Sanchez et al., 1983; Herpin et al., 2002). Several previous studies have detected NO$_3$ pulses lasting for a few months up to one year after burning (Hölscher et al., 1997; Neill et al., 1999; Sanchez et al., 1983) and Mainville et al. (2006) found large and long-term losses in NO$_3$ in Inceptisols under pasture. These results are also supported by hydrochemical studies, which have identified increased NO$_3$ concentrations in both surface water (Parker, 1985) and ground water (Williams et al., 1997) draining disturbed forest areas.

There was no apparent decrease in soil acidity induced by burning and ash input (Figure 4.6 f). An increase in soil pH has elsewhere been reported as the most common effect from slash and burn (see for example Numata et al., 2007; Sanchez et al., 1983). However, McGrath et al. (2001), that reviewed published results from 39 (non Andean) sites, found elevated pH only in pasture soils while there were no significant differences between soil under primary forest, plantations and crops. In addition, similar pH under different land covers, including pasture, has previously been reported for Inceptisols in the Subandes (Plamondon et al., 1991) and elsewhere (McDonald et al., 2002). Depending on the magnitude of the disturbance signal it is possible that the large variability in nutrients in soils of the upper Amazon masks effects of deforestation and burn which similarly for river water previously has been discussed in Sobieraj et al. (2002). However, the clear nutrient enrichments in the swidden soils together with the lack of differences between primary forest soils and soils under agricultural use point towards a rapid loss of nutrients. In the lowland Amazon, even if soils are subjected to chemical degradation, nutrients are commonly higher in agricultural soils compared to primary forests soils for years or even decades following burn. The more intense erosion and faster hydrological pathways in the hilly and steep Subandean environment as compared to the Amazon lowland may contribute to the less impact and appeared shorter duration of effects following deforestation and burn. In addition, in the sampled sites of this study post-burn weather conditions likely reduced the influence from burning since a substantial part of the ashes were removed by wind erosion (visual observation). In a steep and hilly environment of Mexico Giardina et al. (2000a) found that as much as 74 % and 55 % of the N and P respectively had been lost from the combustion residues on the burnt land in less than a month following burn despite the lack of rain fall. The nutrient depletion is likely to be even more severe with the addition of infiltrating rainwater that subject soluble mineral nutrients to rapid leaching.
The discrepancy between farmers’ perception of degrading soil fertility over time and the apparent lack of differences between soils under different land covers may be caused by several factors. For example, most farmers contributing to the collected view on soil fertility were living and working in areas of lower altitudes, which are more exploited and fragmented compared to the location where the largest part of the samples were collected (i.e. premontane area of the upper Sisa basin; Figure 3.2). In addition, the main agents responsible for the perceived decline in production may be controlled primarily by factors other than chemical. For example Müller et al. (2004) found that pasture productivity in the Brazilian Amazon declined despite stable concentrations of base saturation, soil reaction and available P and concluded that pasture degradation was not directly linked to the chemical degradation of soils. Physical and biological factors that may contribute to productivity decline are increases in soil temperature, changes in soil biology and in soil morphology. In the soils of this study land use was shown to alter soil micro-climate with higher soil temperatures in swidden fields and pastures down to at least a depth of 60 cm, compared to the tree-based land covers (27 ºC vs. 23 ºC). A change in soil temperature may affect soil biology and mineralization and ultimately cause losses of available N (Pandey et al. 2010). It may also directly affect production through controlling plant development (Tahir et al. 2005). Vera et al. (2007) reported major differences in the microstructure and porosity in pasture soil compared to that of natural forest in the Venezuelan Andes as well as indications of different activity and type of soil fauna. In tropical soils of Mexico García-Oliva et al. (1999) found that slash and burn and following cropping and pasture caused a decline in soil macroaggregates in favour of microaggregates. The overexploitation with very short durations of fallow as reported by the farmers may inhibit recuperation of soil structure and soil biological functions (Templer et al. 2005). In addition, several other factors that may have an impact on soil production were reported by the farmers (Table 4.2 and 4.3) including a change from multi-cropping systems to monocultivations, increased compactness of soils, and increases in crop disease: “there are a lot more plagues now than before,” “now if you do not cure /add pesticides/ you will not even harvest beans,” “in the virgin forest however you can still grow without cure.”

There may also have been methodological reasons for the measured similarities in soil chemistry under the different land covers. For example, significant differences in soil chemical fertility in the upper centimetres of the soils may not have been detected with the resolution applied in this study due to dilution. Although most studies have reported effects in the upper 10 or 20 cm of the soil, the effects of burning in the study of Alegre et al. (2005) were clear in the upper 3 cm but not at a depth of 10 cm. When applying a spatial approach to investigate differences in soil chemistry there is also a risk of bias from non-random selection of the sampled sites. For example, although there was effort to avoid such deviations, the selected primary forest soils may have
been located in areas of significantly lower chemical fertility compared to the “initial fertility” (i.e. pre-use) of the selected soils of agricultural use. This situation would appear if farmers make a conscious selection of areas to clear and cultivate. The influence from texture, aspect and slope on soil fertility may to a certain extent be recognized by some farmers. In a nearby river basin, Marquardt et al. (2009) found that farmers leave particularly steep land for forest reserves. In both study areas some farmers did refer to texture (sandy = poorer) and in one of the areas (Saposoa) vegetation (tornillo (Cedrelinga cateniformis)= poor vs. shapaja (Scheelea sp ) = fertile) as fertility indicators. This information however, was communicated as observations from resulting post-clearing yield rather than pre-clearing knowledge used for preferential selections of plots to cultivate. In addition, according to the land owners of this study knowledge to make a preferential selection of soils to cultivate is not widespread in the studied basins. Moreover, according to the farmers there are always people driven by their socio-economical status to acquire and clear areas assumed as very poor. Consequently the influence from preferential selection in this study was likely limited which is further supported by the lack of significant differences between land cover classes in terms of texture and also sample site elevation and slope as mentioned before (Section 3.4).

### 4.2.4 Water quality

Farmers reported on a moderate degradation of surface water quality over time and the current status was perceived to be poor to moderate (Table 4.2). They further agreed on a great deficiency in water of adequate quality. The cause according to the farmers is the increase in population which has lead to widespread settling in headwater zones: “there are more people that have settled near the headwaters now and then whatever they do there they contaminate for the rest of us,” the stream is already contaminated now, before no one lived up there and the water was clean, natural”. Upstream activities contributing to contamination were according to the farmers dumping of solid waste, bacterial contamination from human and animal faeces, and agrochemicals (Table 4.3).

#### Table 4.4 Explained variance for a selection of variables in models on stream water chemistry.

<table>
<thead>
<tr>
<th>Model/Variables</th>
<th>K</th>
<th>Mn</th>
<th>Mg</th>
<th>U</th>
<th>HCO₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>PLRS2</td>
<td>73</td>
<td>64</td>
<td>.35</td>
<td>46</td>
<td>36</td>
</tr>
<tr>
<td>MLR</td>
<td>75</td>
<td>48</td>
<td>40</td>
<td>39</td>
<td>31</td>
</tr>
</tbody>
</table>

9 The only significant difference in texture between soil of the different land cover classes in the two areas was less clay content in the secondary forest soils as compared to the recently swidden fields in the Sisa location.
In terms of the influence of deforestation on dissolved major and minor elements, the areal percentage of forest cover in the watersheds was weakly correlated or uncorrelated with the majority of the chemical variables. The exceptions were Mn, U, Mg, HCO₃⁻ and also K, for which the correlation with forest cover was particularly strong (rₛ=-0.8; Figure 4.7 a and c). This indicates that there is a larger displacement of these elements with increasing proportion of deforested land in the drainage areas. The results from the study on upland soils suggest a temporal leaching of K in soils following slash and burn of forest which indicate that increased concentrations also in stream water are plausible (Section 4.2.2). Translocations of K and other major ions to soil solution and stream waters as a result of deforestation and burning is in line with results presented in several previous studies (Ballester et al. 2003, Forti et al. 2000, Williams 1997, Biggs et al., 2002; Forti et al., 2000; Likens et al., 1994; Tripler et al., 2006; Williams & Melack, 1997). However, in the studied watersheds the proportion of forest cover correlated strongly with the relief (rₛ= 0.8; Figure 4.3). Accordingly, the chemical elements that appeared to increase with increasing proportion of deforested land also correlated strongly with the relief (e.g. r, for K=-0.9). In fact, the correlations between the chemical elements and sub-basin relief were stronger than with forest cover (Figure 4.7).

A PLSR² model including all studied physical and chemical variables (Table 3.3) confirmed that the two most important physical controls on water chemistry were forest cover and average elevation. The significant predictor variables for the first principal component in order of decreasing control were: average elevation (loading 0.47) > forest cover (0.45) > average slope (0.40) > elevation at sampling point (0.39) > Ipururo formation (-0.33) > elevation range (0.28) > Chambira formation (0.17) > Juanjui formation (-0.13) > Oriente formation (0.11). These results were similar when running slightly altered models for example excluding the streams affected by dissolution of massive evaporites. Overall the PLSR² model explained 29 % of the variation in the chemical variables and for many individual response variables the explanation degree was higher, a selection is presented in Table 4.4. The only geological formation that co-varied with average elevation (and thus also the same group of chemical elements) was Ipururo. This formation is relatively young and fine-grained compared to the others and commonly constitute bedrock at lower elevations. The control was however much weaker than for relief and thus the average elevation showed to be a significantly better measure of natural controls than the mapped extent of geological formations.
Multiple linear regressions were run for the elements showing strongest correlation with sub-basin forest cover and average elevation and that were among those explained best in the PLSR2 model (Table 4.4). The results revealed that average elevation was the main predictor for all these elements (p < 0.05 for HCO₃ and p < 0.01 for the rest) while forest cover was not a significant control for any of them (p > 0.15). The variances explained by the MLR are presented in Table 4.4.

The results from the analysis of stream water concentrations along the two main rivers and along one of the sub-basin streams supported the results from the sub-basin analysis, in particular for K. Potassium increased in a downstream direction (i.e. with decreasing elevation) along the rivers (Figure 4.7 b and d). This pattern was similar for all measurement events over a year (i.e. for varying discharge; Table 3.4) which indicates that the increasing concentrations along the altitude gradient are persistent at different hydrological regimes.

The sub-basin average elevation serves as a proxy for a combination of undefined variables that may include lithology, overburden, climate and hydrological pathways. The increasing solute concentrations with decreasing altitudes could be caused by a corresponding increase in weatherability and chemistry of bedrock, in overburden thickness (longer and deeper flow paths), in air temperatures (which favour weathering), and a decrease in precipitation (causing a relatively larger influence on stream flow from groundwater). An increasing amount of K-bearing clays at lower altitudes could also contribute. These possible causes are in general agreement with those discussed by others (Caine & Thurman 1990; Drever & Zobrist, 1992; Johnson et al., 2000) that also found a similar increase in solutes with decreasing elevation.

4.2.5 Basin-wide chemical processes

In floodplain sediments of both studied basins concentrations of most chemical elements increased with depth. Two exceptions were pH and P which were stable throughout the vertical profiles (pH shown in Figure 4.9 and 4.10 d). For the other elements concentrations were only stable down to ca. 1 m depth after which they increased gradually reaching peak concentrations before a depth of ca. 1.5 m (Figure 4.9 and 4.10 a, b and c). Thereafter concentrations decreased towards the bottom of the profiles. However, at 2 m depth in Sisa, and possibly also at 1.5 m in Saposoa, concentrations increased again to form a second concentration peak. Close to the base of the profiles, where the anthropogenic influence on element concentrations is expected to be limited (Bölviken et al. 1996), concentrations were similar to those of the upper meter.
Multiple linear regressions were run for the elements showing strongest correlation with sub-basin forest cover and average elevation and that were among those explained best in the PLSR2 model (Table 4.4). The results revealed that average elevation was the main predictor for all these elements (p< 0.05 for HCO3 and p< 0.01 for the rest) while forest cover was not a significant control for any of them (p >0.15). The variances explained by the MLR are presented in Table 4.4.

The results from the analysis of stream water concentrations along the two main rivers and along one of the sub-basin streams supported the results from the sub-basin analysis, in particular for K. Potassium increased in a downstream direction (i.e. with decreasing elevation) along the rivers (Figure 4.7 b and d). This pattern was similar for all measurement events over a year (i.e. for varying discharge; Table 3.4) which indicates that the increasing concentrations along the altitude gradient are persistent at different hydrological regimes.

The sub-basin average elevation serves as a proxy for a combination of undefined variables that may include lithology, overburden, climate and hydrological pathways. The increasing solute concentrations with decreasing altitudes could be caused by a corresponding increase in weatherability and chemistry of bedrock, in overburden thickness (longer and deeper flow paths), in air temperatures (which favour weathering), and a decrease in precipitation (causing a relatively larger influence on stream flow from ground water). An increasing amount of K-bearing clays at lower altitudes could also contribute. These possible causes are in general agreement with those discussed by others (Caine & Thurman 1990; Drever & Zobrist, 1992; Johnson et al., 2000) that also found a similar increase in solutes with decreasing elevation.

4.2.5 Basin-wide chemical processes
In floodplain sediments of both studied basins concentrations of most chemical elements increased with depth. Two exceptions were pH and P which were stable throughout the vertical profiles (pH shown in Figure 4.9 and 4.10 d). For the other elements concentrations were only stable down to ca. 1 m depth after which they increased gradually reaching peak concentrations before a depth of ca. 1.5 m (Figure 4.9 and 4.10 a, b and c). Thereafter concentrations decreased towards the bottom of the profiles. However, at 2 m depth in Sisa, and possibly also at 1.5 m in Saposoas, concentrations increased again to form a second concentration peak. Close to the base of the profiles, where the anthropogenic influence on element concentrations is expected to be limited (Bölviken et al. 1996), concentrations were similar to those of the upper meter.
The identified concentration peaks in the two sediment profiles were most distinct for Hg, Cd, Mn, organic matter (OM) and N and these elements were strongly associated to one another in both basins ($r > 0.8$; Figure 4.9 and 4.10 a and b). Compared to the median of the lowermost four samples, the peak concentrations of Hg were ca. three times higher, those of Cd and Mn at least twice as high, and those of OM ca. 14 times higher. Several other elements (Cu, Co, Cr, Zn, Ni and Pb) followed a similar but less pronounced pattern (Figure 4.9 and 4.10 c). In contrast, grain size and Al did not follow a vertical trend similar to that common to the other chemical elements (Figure 4.9 and 4.10 f and e respectively). Aluminium generally increases with decreasing grain size and can be used as an indicator of the amount of fine particles (clay) in the sediments (Rognerud et al. 2000 and references therein). Thus, the chemical variations were interpreted to be caused by anthropogenic activities, i.e. land-cover or land-use changes, either within the upstream landscape (pre deposition) or in situ at the floodplain sites (post deposition).

Due to the strong co-variation between chemical elements and OM it appeared that the element enrichments were a direct effect from the OM content which would be favoured by the alkaline conditions prevailing in the sediments. However, according to chemical analysis applying pyrophosphate that extracts labile organic acids (e.g. humic and fulvic acids) and elements bound to these, only a small fraction of the total amount of each element could be bound to OM. The amounts were 15 % for Hg, 10 % for Cu, 8 % for Cd, and <6 % for the other elements. In addition, these fractions were similar throughout the profiles, i.e. they did not co-vary with the pattern of total amounts and OM. Thus, although the OM and chemical elements appear to have originated in the same source and have been subjected to the same processes to induce their vertical movement, it is unlikely that the element enrichments were directly caused by the presence of OM.

There was no evidence of basin-wide translocation of trace elements or OM as a result of deforestation and land-use change in the upland soils as indicated by the similar concentrations of chemical elements in the sediments of the two adjacent river basins despite large differences in exploitation degree (see Figure 3.2). Moreover, trace element concentrations, both total amounts and the fraction associated with organic acids, were similar between surface soil under primary forest and agricultural land covers. In addition, for each land cover class there were no differences in ratios of chemical concentrations between surface soil and sub soil. Previous studies carried out in the lowland Amazon (see for example Roulet et al., 2000; Fostier et al., 2000) and in the Ecuadorian Andes (Mainville et al., 2006), have documented an increased Hg export from soils following land-use change which was attributable to increased soil erosion. The discrepancy between observations may be caused by differences in Hg concentrations as well as soil characteristics (e.g. texture,
The identified concentration peaks in the two sediment profiles were most distinct for Hg, Cd, Mn, organic matter (OM) and N and these elements were strongly associated to one another in both basins (rs >0.8; Figure 4.9 and 4.10 a and b). Compared to the median of the lowermost four samples, the peak concentrations of Hg were ca. three times higher, those of Cd and Mn at least twice as high, and those of OM ca. 14 times higher. Several other elements (Cu, Co, Cr, Zn, Ni and Pb) followed a similar but less pronounced pattern (Figure 4.9 and 4.10 c). In contrast, grain size and Al did not follow a vertical trend similar to that common to the other chemical elements (Figure 4.9 and 4.10 f and e respectively). Aluminium generally increases with decreasing grain size and can be used as an indicator of the amount of fine particles (clay) in the sediments (Rognerud et al. 2000 and references therein). Thus, the chemical variations were interpreted to be caused by anthropogenic activities, i.e. land-cover or land-use changes, either within the upstream landscape (pre deposition) or in situ at the floodplain sites (post deposition).

Due to the strong co-variation between chemical elements and OM it appeared that the element enrichments were a direct effect from the OM content which would be favoured by the alkaline conditions prevailing in the sediments. However, according to chemical analysis applying pyrophosphate that extracts labile organic acids (e.g. humic and fulvic acids) and elements bound to these, only a small fraction of the total amount of each element could be bound to OM. The amounts were 15% for Hg, 10% for Cu, 8% for Cd, and <6% for the other elements. In addition, these fractions were similar throughout the profiles, i.e. they did not co-vary with the pattern of total amounts and OM. Thus, although the OM and chemical elements appear to have originated in the same source and have been subjected to the same processes to induce their vertical movement, it is unlikely that the element enrichments were directly caused by the presence of OM.

There was no evidence of basin-wide translocation of trace elements or OM as a result of deforestation and land-use change in the upland soils as indicated by the similar concentrations of chemical elements in the sediments of the two adjacent river basins despite large differences in exploitation degree (see Figure 3.2). Moreover, trace element concentrations, both total amounts and the fraction associated with organic acids, were similar between surface soil under primary forest and agricultural land covers. In addition, for each land cover class there were no differences in ratios of chemical concentrations between surface soil and sub soil. Previous studies carried out in the lowland Amazon (see for example Roulet et al., 2000; Fostier et al., 2000) and in the Ecuadorian Andes (Mainville et al., 2006), have documented an increased Hg export from soils following land-use change which was attributable to increased soil erosion. The discrepancy between observations may be caused by differences in Hg concentrations as well as soil characteristics (e.g. texture, ...

Figure 4.9 Vertical distribution of chemical and physical variables in Sisa floodplain sediments. Dept in cm versus a) OM and N (%), b) Hg (ug/kg), Cd and Mn (mg/kg), c) Zn, Pb, Cr, Cu, Co, Ni (mg/kg) and Fe (%), d) pH, e) Al (%), and f) grain size fractions (%). Position of combustion residues are marked with dashed lines and gravel bed with grey area. Red symbols in b) and c) show Hg and Pb, respectively, in the upper ash layer, and in sediments just above and below it, two years after the main sampling event.
OM content, degree of development and hydrological conditions) that may influence Hg cycling in soils (see in depth discussion in Grimaldi et al., 2008; Oliveira et al., 2001). Of particular importance may be the difference in age between the Andean and lowland soils which has enabled the lowland soils to accumulated atmospheric Hg for a much longer time (Mainville et al. 2006). This is in line with the fact that the median Hg concentrations of the studied upland soils were similar to those considered as background concentrations in the Amazon lowland (Fostier et al., 2000).

![Figure 4.10 Vertical distribution of chemical and physical variables in Saposoa floodplain sediments. Dept in cm versus a) OM and N (%), b) Hg (µg/kg), Cd and Mn (mg/kg), c) Zn, Pb, Cr, Cu, Co, Ni (mg/kg) and Fe (%), d) pH, e) Al (%), and f) grain size fractions (%). Position of combustion residues is marked with a dashed line and gravel bed with grey area. Red symbols in b) and c) show Cd and Co, respectively, in ash layers, and in sediments just above and below it, two years after the main sampling event.](image)
The chemical enrichments in the sediments were likely produced by an in-situ source. In both studied basins, the observed increase in element concentrations occurred directly below horizontal layers of combustion residues, a result of in-situ slash and burn of primary and secondary forest, which had been confirmed by land owners (Figure 4.9 and 4.10). In addition, both sites had been burnt twice and in both profiles, however less prominent in the Saposoa one, the chemical elements exhibited a pattern characterised by two enrichment peaks. The additional sampling two years after the main sampling event confirmed that the increased chemical concentrations occurred in and below the layer of combustion residues. It also indicates that the pattern is similar over large parts of the burnt fields since these samples where taken several meters in a horizontal direction from the original samples (due to heavy erosion of the floodplains). The lack of similar enrichment patterns in the duplicate profile in Saposoa and the Huallaga profile as well as the upland soils may have several causes involving differences in amount and composition of burnt biomass, conditions during burn, erosion and management practises. For the Huallaga profile the main reason is likely the limited time since slash and burn took place (1 year prior to sampling compared to >10 years for the other profiles).

A downward transport in the sediments governed by chemical processes (i.e. leaching) is unlikely because many of the elements exhibiting concentration enrichments (e.g. Cr, Cd and Co) are known to be immobile in alkaline environments. In the review by Bölviken et al. (2004) vertical translocation of elements in floodplain sediments may occur but this concerns relatively mobile elements in non-calcareous areas greatly impacted by acid rain. It is therefore suggested that the active transport process causing the particular concentration pattern of chemical elements in the floodplain sediments was physical translocation of particles originating in the combustion residues. This may have been mediated by infiltrating and percolating rain water as well as water from flood events. Leaching of small particles from ash has previously been reported by Stromgaard (1991). Due to the strong co-variation between in particular Mn but also Fe and many of the other chemical elements it is possible that sorption onto oxides produced during and/or following forest burn may be the principal control of post-burn translocation of trace elements within the sediments.

The radiometric dating did not return any information on sediment age since all measured concentrations were below the detection limit (0.85 Bq $^{137}$Cs/kg). The cause may be dilution, such as intermixing with older sediments during transport (e.g. river bank material). Age markers could however be established by combining the known depth of combustion residues in the profiles with the information on the year of slash and burn as provided by the farmers. This also enabled estimates of plausible post-deforestation average sediment accumulation rates of between 4 and 14 cm per year.
4.2.6 Livelihoods (forest products, climate & water quantity)

The reduction and degradation of forest as described in Section 4.1 has lead to a concurrent degradation and loss of habitats for wild life and a decline in the diversity of vegetative species (Table 4.2). Traditionally these have constituted major components in the lives, livelihoods and worldviews of local people (Rengifo 2007). Today, forest products such as wild game, fire wood and medicinal plants are reported difficult to obtain. When discussing wild animals in particular, all interviewees agreed on a major decline from an abundance to virtually non-existent: “nowadays, if one does not go deep in to the mountains there is none,„there is no longer any to be found‟, and: „„now we almost do not know about animals”. Also the amount, size and diversity of fish in the local freshwaters were perceived to have greatly decreased: “we are talking about 20 years ago, wow, then there were loads of fish„„you could bring them home in sacks”. The time indication for introduction of the change given by this farmer was shared among farmers and concurred with that of most changes; all were perceived to have emerged recently, largely over the past two decades (Figure 4.12).

The vast majority of interviewed farmers (96 %) strongly believe that the local climate has change considerably to drier and warmer, and that there has been an associated major decline in discharge of rivers and streams (Table 4.2). The farmers are certain of a direct link between climate and deforestation, in particular of forest in riparian and headwater areas. They believe that forest is the main agent in creating rains and discharge, in regulating air temperatures and in the production of fresh and pure air. Many farmers (41 %) also reported that the seasons are less distinct nowadays and that winter (wetter period) has decreased in favour of summer (drier period): “what before the rains and the summer were in specified dates now has changed„„now it is a disorder”. Rains were described as scarce resulting in low water levels and periodical draughts. Several described the common existence of draughts as a recently introduced feature: “now there are draughts, before one did not know about draughts”. One farmer illustrated the change from the 1960’s with his words: “you could not cross /the river/ with boots even when it was summer, the river was big„„today when it is only a little summer, you put on your boots and cross the water, and then it is dried up, we will end up without water”.

Farmers’ opinion that the local climate has changed to warmer and drier is in line with findings in natural science. Villar et al. (2009b; 2006; 2009a) confirm a decrease in mean precipitation since the 1980’s as measured near the outlet of the Amazon Basin as well as of the Peruvian Amazon, and that discharge behaves with conformity. In addition, recent findings by Lavado et al. (2011) found the discharge of Huallaga River (Figure 3.2), the recipient for waters of the Saposoa and Sisa basins, to be decreasing over time. In the western Amazon, in particular, a prolongation of the drier periods is likely in the future (Kitoh et al. 2011). According to Villar et al. (2009b) the changes in rainfall are governed by large scale changes in ocean and atmospheric conditions and they refer to a possible influence also from deforestation. In the review by D’Almeida et al. (2007) it is shown that at least on macro -scale, deforestation cause a decline in modelled rainfall amounts.

Future scenarios based on global climate change and on continued deforestation strongly point towards continuously drier and warmer conditions in the Amazon Basin with increased frequency of extreme events such as floods and draughts (Medvigy et al. 2011; IPCC 2007; Kitoh et al. 2011). With a successively drier climate an intensified migration towards more humid
Livelihoods (forest products, climate & water quantity)

The reduction and degradation of forest as described in Section 4.1 has led to a concurrent degradation and loss of habitats for wildlife and a decline in the diversity of vegetative species (Table 4.2). Traditionally these have constituted major components in the lives, livelihoods and worldviews of local people (Rengifo 2007). Today, forest products such as wild game, firewood and medicinal plants are reported difficult to obtain. When discussing wild animals in particular, all interviewees agreed on a major decline from an abundance to virtually non-existent: "nowadays, if one does not go deep in to the mountains there is none,,,there is no longer any to be found," and: ",,now we almost do not know about animals." Also the amount, size and diversity of fish in the local freshwaters were perceived to have greatly decreased: "we are talking about 20 years ago, wow, then there were loads of fish,,,you could bring them home in sacks." The time indication for introduction of the change given by this farmer was shared among farmers and concurred with that of most changes; all were perceived to have emerged recently, largely over the past two decades (Figure 4.12).

The vast majority of interviewed farmers (96%) strongly believe that the local climate has changed considerably to drier and warmer, and that there has been an associated major decline in discharge of rivers and streams (Table 4.2). The farmers are certain of a direct link between climate and deforestation, in particular of forest in riparian and headwater areas. They believe that forest is the main agent in creating rains and discharge, in regulating air temperatures and in the production of fresh and pure air. Many farmers (41%) also reported that the seasons are less distinct nowadays and that winter (wetter period) has decreased in favour of summer (drier period): "what before the rains and the summer were in specified dates now has changed,,,now it is a disorder." Rains were described as scarce resulting in low water levels and periodical droughts. Several described the common existence of droughts as a recently introduced feature: "now there are droughts, before one did not know about droughts." One farmer illustrated the change from the 1960’s with his words: "you could not cross /the river/ with boots even when it was summer, the river was big,,,today when it is only a little summer, you put on your boots and cross the water, and then it is dried up, we will end up without water." Farmers’ opinion that the local climate has changed to warmer and drier is in line with findings in natural science. Villar et al. (2009b; 2006; 2009a) confirm a decrease in mean precipitation since the 1980’s as measured near the outlet of the Amazon Basin as well as of the Peruvian Amazon, and that discharge behaves with conformity. In addition, recent findings by Lavado et al. (2011) found the discharge of Huallaga River (Figure 3.2), the recipient for waters of the Saposoa and Sisa basins, to be decreasing over time. In the western Amazon, in particular, a prolongation of the drier periods is likely in the future (Kitoh et al. 2011). According to Villar et al. (2009b) the changes in rainfall are governed by large scale changes in ocean and atmospheric conditions and they refer to a possible influence also from deforestation. In the review by D’Almeida et al. (2007) it is shown that at least on macro-scale, deforestation cause a decline in modelled rainfall amounts.

Future scenarios based on global climate change and on continued deforestation strongly point towards continuously drier and warmer conditions in the Amazon Basin with increased frequency of extreme events such as floods and draughts (Medvigy et al. 2011; IPCC 2007; Kitoh et al. 2011). With a successively drier climate an intensified migration towards more humid
environments can be expected which is also indicated by the fact that several colonist farmers reported climate as a reason for migration from the drier Andean and coastal areas towards the jungle (Section 4.2.1) and is also illustrated by one of the colonist farmer’s thoughts presented in Figure 4.13. In the short-run this is likely to increase pressure on the natural environment of the highland jungle and in the long-run it may even involve a migration from this region to others that are less severely impacted by deforestation and climate change.

"When I came here there were abundant rains …after that they gradually withdrew and it did not rain any longer, there was a lot of water in the streams and in the rivers too, there was a lot of water but it is not like that anymore, the stream is dry, there is no water, there is not even enough water to wash oneself. Trees, that is what is needed here, because you know when it doesn’t rain everything dries up. There is nothing, if one plants something eatable like beans, corn, it all dries up. When there is water there is food and when there is no water there is nothing. Today when the waters dry up there is not even enough to plant, even less for rice, nothing, we will have to move to another place soon you know, many people have already left, when the summer came. They say they move to other places where there is a lot of virgin forests, several from here has left already. Yes, we will have to leave, when, when there is nothing left."

Figure 4.13 A colonist farmers thoughts about water availability and the future.

The changes that have been introduced in the environment were reported to have affected life quality in a negative way (Table 4.3). The two most frequently mentioned effects of deforestation that have direct impacts on the lives of farmers were the decline in rainfall (49 %) and the warmer air temperatures (43 %). Thus, the perceived quality of life is closely connected to the quality of rural livelihoods. As informed by the farmers climate to a great extent control yield which in turn affects income, food quality and overall standard of life. In addition, 20 % mentioned production decline as a direct cause to an inferior quality of life. Other contributing factors were the lack of discharge, fresh air, hardwood and wild animals. The changes in climate and increased pressure on the land have also given rise to conflicts among farmers and communities. Disputes commonly arise from disagreements on the position of land boundaries, invasions of already claimed land and water scarcity: “conflicts always come in summer times, almost every year, all the time when it is summer, when there is less water”. While most conflicts were reported to be on the level of oral disputes, threats, kidnappings, animal thefts, vandalism of crops and armed fights (machete) were also mentioned. Due to the negative effects deforestation introduces in the environment and its major impact on life quality and intimately connected livelihoods, most farmers (92
% viewed the process primarily as negative (92 %). However, at the same time forest clearing is perceived as essential for survival. The situation was perceived problematic as is illustrated by the words of a selection of farmers in Figure 4.11, 4.14 and 4.16.

"/if we couldn't clear forest/ we would be screwed because we wouldn't have anything to eat. We need to/clear forest/, to be able to survive, otherwise, we would have to go and steal, people wouldn't be able to work."

Figure 4.14 A farmer's response when asked if further deforestation is inevitable.

Preliminary results from the interview material reveal that farmers in general perceive that forest brings few direct benefits (indirect environmental services are discussed above). More than one third mentioned that forest only serve them if it is cut down to use the land for food production and few (< 10 %) had an additional income from forest products. Also the direct benefit and use of other compartments in the environment appear to have decreased. For example, one third of the farmers stated they rarely or never use the rivers and streams, and fishing was only practiced by 24 % of the households. Thus, the results indicate that the farmers to a certain degree have accepted and adapted to the decline in availability of forest and forest products (i.e. decreased use and importance). For native farmers this would involve a process of increased separation from local traditions as also indicated by their lack of knowledge in indigenous languages. For colonist farmers, despite these changes, most are likely to currently live in conditions with more access to these products (which they are also less traditionally linked to) than in their home regions. In deed, several of the environmental factors were perceived to have changed to a greater magnitude by native farmers as compared to colonists (Figure 4.15). In addition, the bulk of farmers that found the changes insignificant, i.e. a rating of 0, was often accounted for by colonists. The colonist farmers were also more positive towards irrigation and selective logging. While 89 % and 27 % of the colonist farmers respectively found these activities positive the figures for natives were 48 % and 8 % (p <0.01 and p <0.05 respectively). These differences in opinions raise concerns whether colonist farmers are less preoccupied and thus possibly less motivated to collaborate with actions that mitigate the current negative trend in the environment. Although the discrepancy between the two groups may also be caused by the fact that native farmers have spent longer time in the high jungle and thus are likely to have a different reference or the initial condition or characteristics of the natural resources.
Preliminary results indicate that the farmers perceive themselves as relatively passive in the process of environmental degradation. They rated their own affect on the quality of water, soil and forest to be small to moderate, 1.0, 1.7 and 1.8, respectively. In contrast, they perceived that farmers in general (i.e. “other” farmers) affect stream waters and soils to a larger degree, 2.6 and 2.4, respectively, (i.e. moderate to high) and the statement that people care for their soils was only assigned the rating 0.9 (little). Thus, farmers need to become more aware of their own role in affecting the environment.

Figure 4.15 A selection of environmental changes that were assigned different ratings (p<0.05) by native (grey) and colonist (black) farmers. Scale: 1-4 small to very large decline; 0= no change or increase.

“„what could that be, something more /contemplating/ „personally I don't know anything, what I do know is to worry, tomorrow what I will do is to take my shovel and my machete and I will see what I will do „I think about the future but I don't know what to do about it.”

Figure 4.16 Final remarks by one of the farmers when asked if there was anything more to add to the discussion on environmental degradation.
5. CONCLUSIONS

Apart from the short-lived nutrient enrichment following burning of biomass on fields where forest recently was cleared and burnt and the in-situ downward translocation of chemical elements in alluvial soils, there were no chemical characteristics of upland soils, stream waters and floodplain sediments of the two studied river basins that could be associated with deforestation and land use change. The chemical quality of these media was similar in the two basins despite a large difference in exploitation degree. The principal geochemical controls appear to be natural and composed of a combination of lithology and topography and associated properties. Inhabitants of the river basins however reported on a substantial degradation of the environment which has become notable mainly over the last two decades. The drier climate was reported to be the principle cause for a negative change in rural livelihoods.

In detail:

- The Subandean soils (Inceptisols and Entisols) were significantly enriched in nutrients compared to lowland Oxisols and Ultisols. In addition, the chemical fertility exhibited a much larger range in the pre-montane soils (Paper I).

- There were no differences in concentrations of macro- and micro-nutrients or other indicators of chemical soil fertility in soils used for agriculture (pasture, coffee plantations and fallow) compared to nearby primary forest soil. The result is valid for a location with eutric soils (i.e. small variation in fertility) as well as for a location with soils ranging from dystric to eutric (i.e. large variation in fertility; Paper I).

- The principal control on the chemical composition of soils was soil texture. The amount of sand was positively associated with exchangeable Al while clay and silt with a large number of variables associated with high soil fertility (Paper I).
● Slash and burn of forest cause short-lived enrichments in a few nutrients, mainly NO₃ and K. These nutrients were otherwise frequently available in concentrations that may limit soil fertility (Paper I).

● The extent of forest cover decreased with decreasing altitudes as a result of human activities. Sub-basin forest cover co-varied with the concentrations of several solutes in stream water, in particular K, although forest cover was not a statistically significant predictor (Paper II).

● In both studied river basins watershed average elevation was the principal control of dissolved elements in stream water with increasing solutes, foremost K, down the altitude gradient (Paper II).

● It is proposed that the near exponential increase in solute concentrations down the elevational gradient, ranging from steep mountain ridges to flat valley bottoms is caused by a similarly continuous physical change in a downstream direction such as increasing depth of overburden and associated changes in hydrological pathways (Paper II).

● The observed increase in weathering rate with decreasing elevation within the Subandean river valleys is reversed compared to the regional pattern (Amazon Basin scale; Paper II).

● The results illustrate the importance of including indices of natural controls in studies of effects of land-cover and land-use to not misinterpret the impact from human induced changes (Paper I and II).

● There were no differences in concentrations of potentially toxic elements (e.g., Cd, Hg, Ni and Pb) in soils used for agriculture (pasture, coffee plantations and secondary forest) compared to nearby primary forest soil (Paper III).

● The chemical composition of alluvial deposits were similar in two adjacent drainage basins despite large differences in exploitation degree (1/3 versus 2/3 of original forest cover cleared; Paper III).

● In-situ slash and burn has caused vertical displacement and enrichments of chemical elements, including several potentially toxic ones (e.g. Hg and Cd) in floodplain sediments (Paper III).

● As a result of deforestation and agricultural land-use local inhabitants perceive that the natural environment has been subjected to profound changes that largely have appeared over the last two decades (Paper IV).
● The most severe changes that has been introduced are the declines in forest availability, wild animals, fish, and a change in climate with increased air temperatures, decreased precipitation and discharge of rivers and streams and less regularity in seasons (Paper IV).

● Native (non-indigenous) farmers perceived several of the environmental changes to be greater in magnitude as compared to colonist farmers (Paper IV).

● Deforestation and associated changes in the environment has according to farmers a large negative impact on the quality of life which is closely related to rural livelihoods (Paper IV).
RECOMMENDATIONS

The heterogeneous character in terms of soil acidity and nutrient levels of soils in the Subandes demands for site specific management techniques, e.g. in terms of crop selection, fertilizer input and overall measures to improve soil fertility, in order to reach long-term satisfactory production levels which are necessary for rural development and to reduce further deforestation of areas holding primary forest. Thus, mapping of the spatial distribution of soil fertility constraints would be of benefit.

In swidden farming nutrient retention should be improved substantially. Observed current practices allow for erosion and leaching of nutrients. Ashes that contain a substantial part of the nutrients previously stored in the above ground vegetation should be incorporated quickly into the soil and a vegetation cover should be established as soon as possible after burning. Introduction or increase in more nutrient conserving practises, such as slash and mulch and agroforestry, is recommended.

A selection process of which lands to preferentially clear and cultivate could be developed based for example on differences in texture (preferential selection of soils high in clay) and vegetation composition. Several other studies have pointed out the importance of selecting fertile soils (see for example Farella et al. 2007) and Vera et al. (2007) argue that it is even more important than the introduction of agroforestry practises. Although it is likely to be accomplished to some extent already by experienced farmers, at least regarding slope and texture, it could be developed further and communicated to the new colonists arriving from other ecological regions. However, to be successful in limiting the extent of deforestation this measure need to be carried out in parallel with recuperation of degraded soils and political initiatives on national and regional levels due to the continuously increasing pressure on land.

Other processes than chemical degradation may be important in the control of fertility in Subandean soils. Such processes may for example include weed invasion, accumulation of pests and diseases, and changes in soil biology and soil morphology. Thus, spatial and temporal studies where these factors are studied simultaneously are recommended to give further insight into their relative controls.

To further determine the characteristics of land-cover it is recommended that images of at least a similar resolution to that of SPOT data (i.e. 10 m) are used due to the highly heterogeneous land-cover pattern.
In general, farmers living in villages where local NGOs have an influence (e.g. through cooperatives for coffee and cacao production) have a better understanding of processes in the environment. In addition, more measures promoting sustainable development have been introduced in these villages, for example compost systems, functional toilets and production of organic fertilizers. Thus, an increased interaction between villages and NGOs could promote improvement of the socio-environmental conditions in rural areas.

In many of the villages in the highland jungle coffee and cacao plantations are becoming increasingly important. These crops have a high potential of bringing substantially larger profits to the producers compared to for example corn and cotton. The effects of this change on livelihoods and the natural environment are uncertain. Preliminary results from the Poverty and Environment Network’s (PEN) study suggest that at least on a global level high income households are responsible for 30% more deforestation than low income households (CIFOR 2011). On the other hand many cooperatives promote the production of organic beans and do not accept conversion of primary forest to plantations. In addition, as mentioned above farmers involved in these cooperatives generally have a deeper understanding of environmental processes and to a larger degree use organic fertilizers compared to other farmers (unpublished data Lindell 2007).

Currently, there is a process of transformation from shifting cultivation to a more or less permanent production (foremost in the valleys) which increases the demand of fertilizers and pesticides to uphold yields. With increasing use of agrochemicals and the lack of functional riparian zones there is an overhanging risk of severe degradation of surface waters.

To face the current and future climate challenges it is of great importance to enforce measures that mitigate climate change and that favour a stable water supply throughout the year. Today, large extents of basin valleys are covered by rice cultivations which are extremely water demanding. These cultivations serve as an example of unsustainable agriculture which should be converted to cropping systems that are adapted to the decreasing trend in water availability and thus are viable in a longer perspective. However, this will require a change in conditions for livelihoods in the valleys together with a change in farmers' attitudes. Currently most farmers perceive the positive effects of irrigation (i.e. increased yield) to exceed the negative. In addition, to alleviate conflicts it is important to elaborate and enforce regulations on water use, especially during drier parts of the year.

It is important that the above discussed and proposed mitigation measures are carried out in cooperation with the local inhabitants. Their active participation in the process is important due to several factors. First, they hold a lot of information about the nature of the environment and rural conditions for
livelihoods. Second, the people constitute key stakeholders and thus their attitudes and perceptions are important in the work of identifying priorities and measures that are acceptable among the inhabitants and that could contribute to improved livelihood conditions and a more sustainable interplay between them and the natural environment. To take into consideration the views and the knowledge of the local population in the elaboration of development plans is thus essential for the feasibility of socio-environmental efforts, in particular in this kind of areas where governmental control to a certain extent is limited. In addition, people are likely to have different prerequisites, needs and preferences. Thus, the recognition of differences in perceptions and attitudes between and within different stakeholder groups, e.g. between native and immigrant communities, and between upland and valley areas, is important to increase sensitivity and flexibility of development measures.

In interviews with local populations a qualitative approach or a combination of qualitative and quantitative approaches is recommended to achieve an accurate and in-depth understanding of perceptions and attitudes. Because of the large variation in knowledge and abilities between farmers the interviews should allow for flexibility. In addition, an extensive usage of images to facilitate the explanation of concepts and to define settings or objects is recommended.

Further, it is important to develop the trust between local populations and governmental institutes as well as non-governmental organizations. Many farmers mistrust in particular the government and assess the risk of long-term commitments, e.g. tree plantations, as high. Farmers’ perception of being subject to exploitation was notable by their first reaction when encountered with the sampling team of this study in the field. They commonly feared it would bring them loss, for example in terms of land. This bear witness of how the rural people (both in the highland jungle and in the native regions of new settlers) have been treated in the past and that it still affects their way of thinking and likely also the characteristics and planning of agricultural activities.

Many rural people encountered during the development of this thesis were interested in increasing their active participation in measures to improve the condition of the environment. See Figure 3.24 for an excellent example of this kind of initiative. However, they expressed their lack of knowledge on how to proceed. For some kinds of measures there is assistance available, free of charge or at low cost, however, their existence and ways to take part of these programs and benefits need to be better communicated to rural areas, in particular remote ones. The participation is not uncommon to involve travel (to the cities) which demands for expenses and time. Moreover, if there is mistrust or uncertainties that the actions will bring benefits to the
communities or individuals (see discussion above) it is not likely they will be pursued.

To leave the fate of the remaining intact forests entirely or predominately in the hands of smallholder farmers, many of which live in extreme poverty, only have a few years of education and thus lack adequate reading and writing skills, and that frequently have little knowledge on global processes, would either be naive or highly irresponsible. Local population should instead be regarded as a valuable resource that with a correct approach are capable of assisting in the protection of forests and recuperation of degraded land. The overall strategic plan, assistance with training in sustainable management and consensus making within and between communities, and funds or other incentives need to be provided by regional, national and international agents.
Prologue and gratitude

Sometimes things come about that seem to turn your life upside down for a while. This happened to me some years ago. In my case the temporary difficult time showed to result in several years of working with a dream project, something that I never had ambitions for or even fantasised of. It just appeared in front of my feet. The project was continuously developed from my curiosity, drive and collective experience from previous works, supported by continuous discussions with Mats, “my professor”. Mats, this thesis was enabled by your courage, open-minded attitude and absence of prestige, qualities that I highly value. I don’t know what I did to deserve your overwhelming trust in my abilities. Moreover, your support never failed over the years, even if you at times had doubts you never revealed them to me which was of great help on my journey. When I occasionally had times of wonder your generous feedback made me think “Hey, if my supervisor believes in me why shouldn’t I believe in me too”. We have discussed endlessly on scientific matters, many are the times when I have nearly lost my voice from visiting your office. I appreciate that you never tried to change the way I am and that you let me follow my personal path. Thank you also for being so dedicated. Thus, it is with great ease that I assign a gold medal in supervising to you professor Mats Åström.

Over these years I have had several adventures in the rainforests of Peru. For me these have been real adventures, and although nothing compared to the experiences of explorers, for me it implied a fair amount of hardships, like being eaten by mosquitoes, waking up every hour due to sleeping on a hard chilly wooden floor, or not falling asleep at all due to fierce looking spiders in the roof, eating soup cooked on chicken intestines or chicken feet, crossing partly constructed bridges over gushing rivers, being rained-in in the middle of nowhere, driving on thin planks to cross a large ditch in the road or driving on slippery mud just some decimetres away from a scarp, or loosing the breaks of the car and not have it stop for several kilometres, not to mention the diseases, tropical eye inflammations at several occasions, stomach germs, nail fungus, Further, negotiating with armed rangers, spending nights in villages where terrorist flags recently had been spotted in the surrounding mountain peaks, among other sweet little things. I appreciate my students (and my father when he visited during sampling) for reminding me that working in this environment is not trivial. However, don’t take this as complaining, everything worked out surprisingly well and IT WAS ALL WORTH IT! I strongly believe that the greater the effort, the greater the experience and the more special moments you live and remember. And, sometimes I did have to pinch

10 although you are worth something nicer, the expression is merely symbolic,
myself repeatedly too see if I really was there (in the highland jungle that is,,not in my bunker at university). I feel privileged and I am truly grateful for this experience. See Figure P1 to P4 for some moments on my journey.

Having said what is said above it is easy to understand that I would not have been able to do the field work of this thesis on my own. The guides and assistants that have supported me have been essential for the quality of the data. Foremost Welinton, I don’t think there are too many guys that would have followed me on these escapades, especially after being bitten by a rural dog and getting various infections from helping me with water sampling in creepy waters. ♥ Also, Nohemi, who at times let her kitchen turn in to a laboratory and whose fridge was then filled up with all kinds of samples. Willy and Jacki are another set of V.I.Ps that accepted my ambitious work schedule and performed their tasks with excellence. Last but not least I highly appreciate all the farmers that I have come across during this project. Despite the sometimes seemingly strange and perhaps pointless activities on my agenda, most put in their time and work to make me achieve my goals.

At uni there are so many people that have brightened my days (and some evenings!). Yes, I refer to YOU! *** The ones that have contributed most to my scientific pondering are Anna, my room-mate for many years (together with her dog Ester), Neus on our swim-dates and Sofie on our walk-dates. In the beginning there were also Pernilla, Ulf and Christian, you left too soon. To my assisting supervisors: Pasi, I was always more confused when I left your office than when I entered,,thank for being positive and generous with advise, Tommy, you are nice to have around, and Marianne, you welcomed me to put one foot (or at least some toes) on “the other side”, thank you for that and for being so enjoyable to work with.

Further, I thank Per-Anders Lundh at the publishing company Atremi (www.atremi.se) for giving me an excellent introduction to Adobe InDesign, a tool I have missed throughout my professional career, and my brother Olle, the Aussie art director, who helped me make two images more professional-looking. Thanks also to all that have read and commented on my work!

Finally, Milo Wayra, the reason for cancellation of my world tour, thank you for the time (year 2010) when I was obliged to set my brain at 100 % motherhood mode„„, I so needed that ☺. Life would be less without you.

I do not know what will come up next but I’ll see you out there!

Lina

PS 1: And mum I love you too. I appreciate that you are always there for me whenever I need to reflect on life in general.
PS 2: A few extracts from discussions with farmers,

Me: "Is there anything else you would like to say, something that I have forgotten to ask?"

Farmer #1: "I rather would like to say that you should always remember these forgotten villages, that you should come and visit us, and by the way you for example, where could you come from? Why have you come to this place so far away,?"

Farmer #2: "well Engineer, personally I would like to thank you for your kindness to have come to my humble home to interview me. I am proud over that you have given me some idea on how to protect the forests and avoid deforestation and for that I feel somewhat happy, I am satisfied with what you have given me."

My assistant: "What is better today compared to 20 years ago?"

Farmer: "well, that 'the gringa' comes and visits us now, it would be better if she should stay and live here, I welcome that 'miss gringa' has come again to visit these parts, two years later she has come again to see the basins of rivers and streams. I'm very grateful that she has come to see us over here again, hopefully she will not forget this village."

Me: "Do you think that population growth is good or bad?"

Farmer: "It is good."

Me: "And why do you think it is a good thing?"

Farmer: "it is good because, well, /thinking/ oh Engineer, this thing is like a puzzle."
Figure P1. The most hardworking guides that accompanied me throughout all field studies.

Figure P2. Me in the vicinity of Yurimaguas (left) and two of the master students, Elin (upper right) and Karin (lower right).
REFERENCES


Figure P3. Jungel flower pot "loggers attack police with bullets" (left). Rutine road control for drugs (upper right). My fantastic reception at the congress in Tarapoto 2008 (lower right).

Figure P4. River transportation in the jungle (top). Competition from a curious cow at sampling site (lower left) and simultaneous TV/radio interview (lower right).
REFERENCES


Escobedo, R. T., 2004. Zonificación ecológica económica de la región San Martín – Suelos y capacidad de uso mayor de las tierras. San Martín, Peru: Gobierno Regional de San Martín, Grupo Técnico de la ZEE, Instituto de Investigaciones de la Amazonía Peruana, IIAP.


FAO, 2011a. The state of forests in the Amazon Basin, Congo Basin and Southeast Asia. Rome, Italy: FAO.


Kitoh, A., Kusunoki, S., & Nakaegawa, T., 2011. Climate change projections over South America in the late 21st century with the 20 and 60 km mesh Meteorological Research Institute atmospheric general circulation model (MRI-AGCM). *Journal of Geophysical Research-Atmospheres*, 116;(art. no.). D06105


APPENDIX 1

ERRATA

Paper I

- Fig. 3, 4 and 5. The text should read: “Median is marked by a line and average by +”.

- Table 5. The prefix for Zn should be 2 (i.e. Zn\textsuperscript{2}P).

Paper II

- Fig. 5. Sb should not be displayed (note that this has no impact on the other parts of the Figure).

Paper III

- Fig. 1 a. Scale should read 0, 1000 and 2000km.

- Fig. 2. Unit for Fe should read %.

- Table 2. DL for Cd with the Na-pyrophosphate leach should read 0.02.

- Page 1098, line 18 from above. The text “with sediment ‘age’ and depth” should read “with successively increasing time since deposition (sediment ‘age’) with depth”.

- Page 1100 List of elements should include Cr and not Mo.
STUDENT REPORTS

Master Degree thesis projects (upper four students) and Minor Field Study projects supported by grants from Sida\(^1\) (all) performed within the scope of this thesis and supervised or co-supervised by L. Lindell:


- Sandström, E., 2008. *The state of the environment and child health in four villages in the department of San Martin, Peru - The association between the quality of stream water used for drinking and diarrhoea prevalence in children under the age of five*. University of Kalmar.

---

\(^1\) Swedish International Development Cooperation Agency
AWARDED GRANTS

Grants that contributed to the development of this thesis:

- Sida\(^1\)/Sarec u-forsk, *Research grant* (2008): 490 000 SEK.
- Carl-Fredrik von Horn Foundation via the Royal Swedish Academy of Agriculture and Forestry (2007): 80 000 SEK.
- Sida\(^1\)/Sarec u-forsk, *Planning grant* (2007): 74 790 SEK.
- Bengt Lundqvists Minne Foundation: (2007): 30 000 SEK.
- Helge Ax:son Johnssons Foundation (2006): 30 000 SEK.

\(^1\) Swedish International Development Cooperation Agency
ASSISTING COLLEAGUES

- WWF\textsuperscript{1} Peru Programme Office (Document no. 435-05-WWF-PPO), Lima, Peru.
- AMRESAM (Asociación de municipalidades de la región San Martín), Tarapoto, Peru.
- EMAPA (Empresa Municipal de Agua Potable y Alcantarillado San Martín S.A.; Eng. R. Prieto), Saposoa Peru.
- Municipalities of Tingo de Saposoa, Huallaga and El Dorado, San Martín, Peru.
- Capirona, Tarapoto, Peru.
- Cedisa, (Centro de Desarrollo e Investigación de la Selva Alta) Tarapoto, Peru.
- ICT (Instituto de cultivos tropicales), Tarapoto, Peru.
- The soil laboratory (Laboratorio de suelos), The National Agrarian University, La Molina, Lima, Peru (R. Bazan T.).
- Åbo Akademi University, Åbo, Finland (P. Österholm).
- Risø DTU National Laboratory for Sustainable Energy at the Technical University of Denmark, Roskilde, Denmark (P. Roos and S. Nielsen).
- Stockholm University, Stockholm, Sweden (I. A. Brown).

\textsuperscript{1} World Wide Fund for Nature