BENTHIC MACROINVERTEBRATES AND LOGGING ACTIVITIES: A CASE STUDY IN A LOWLAND TROPICAL FOREST IN EAST KALIMANTAN (BORNEO, INDONESIA)

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Table of Contents

Abstract

At the beginning of the 21 century, the conservation of biodiversity and the sustainable use of natural resources remains a matter of concern. Within this framework, the aim of this research was to study the effects of logging activities on ecological water quality indicators in a tropical forest. The study was undertaken at both local (species/habitat) and landscape (watershed) scales. The study took place on Borneo Island, in East Kalimantan province (Indonesia), in a state-owned timber concession, on an area of 85 km^2.

In order to study the impact of logging activities at landscape scale, five satellites images (1991, 1997, 1999, 2000 and 2001) were examined. The ecological water quality was evaluate by a biological and a habitat assessment, which were performed at each stream reach. The biological assessment constituted in collected benthic macroinvertebrates. This protocol was conducted at 23 sampling sites on headwater streams in order to compare the impacts of logging in logged area versus unlogged area. Logged area were grouped by the time interval after logging. We examined several groups: recently logged (during logging and until 6 months after logging), 1 to 3 years after logging and, 4 to 5 years after logging and relogged for a second time. Two field seasons occurred in June-August 2000 and April-May 2001. During this eight months time interval, most of the timber concession was relogged for a second time, as a result of the decentralisation process at government level.

The research took four years and the following main results have been obtained. Logging activities at landscape scale were quantified by the total length of logging roads. This underlined the intensification of the logging activities from one satellite image to the other over the time (from 1991 to 2001). Vegetation classification and vegetation index (NDVI) could not be used to assessing the impact of logging activities on forest quality because of the homogeneous forest cover in the study site (no visible patches).

Benthic macroinvertebrates and environmental variables were considered an ideal tool to assess the ecological water quality in the study site. Macroinvertebrates richness was high with 115 taxa mainly identified at family and sub-family level (genera for Ephemeroptera), but abundance was low (mean density of 770 individuals per square meter, ranging from 86 to 2130). Multivariate analysis highlighted that the size of the streams and the impact of logging activities played an important role in ordinating the samples. A co-inertia analysis demonstrated that benthic macroinvertebrates and environmental variables were found to be strongly related to each others. The main results indicated that macroinvertebrate density, richness, diversity, composition and functional feeding organisation responded to logging activities. During and six months after logging, macroinvertebrate density was higher and diversity indices were lower compared to the reference samples (unlogged situation). One to three years after logging were found to be the most disturbed situation, indicated, among other things, by an even lower diversity indices. Environmental variables responded to logging activities by: an increase in canopy opening, water temperature, amount in fine sediment and flow velocity and by a decrease in Fine Particulate Organic Matter (FPOM). The stream ecosystems seemed to recover 4 to 5 years after logging in absence of ongoing activities, density and diversity seemed similar but benthic macroinvertebrate composition is different compared to reference unlogged situation. Among the 115 taxa identified during the study, several were indicator taxa, meaning that they characterised the impact of logging activities at a given time. Indicator taxa were grouped in five categories: «open canopy» taxa (*Platybaetis*, Lepidoptera, Hydropsychinae); «sensitive» taxa (e.g. *Caenodes*, Limonidae, *Potamanthus*, Perlidae, Philopotamidae); «pulse» taxa (e.g. Psephenidae, *Jubabaetis*, *Platybaetis*, Megaloptera, Glossossomatidae) ; «recovery» taxa (e.g. *Labiobaetis*, Helicopsychidae, Platystictidae) and «adaptive» taxa (Diplectroninae, Simuliidae, *Isca*).

A Tropical Stream Concept was proposed to take into account the paucity of shredders collected in the headwater catchment streams. The higher decomposition rate and terrestrial shredders provides the Fine Particulate Organic Matter as direct input from the washing out of the catchment during rainy events.

In summary, macroinvertebrates can be considered excellent indicators, which were successfully used in this tropical environment for both objectives: they assessed biodiversity as an element of forest sustainability and they assessed disturbances due to logging activities, with the advantage to be indicative of recent and past events. Further research is proposed to test the identified indicator taxa to other regions in Borneo, to valid them and to prepare a simplified key to be used by local institutions as a tool for monitoring ecological water quality.

Résumé

En ce début de 21ème siècle, la conservation de la biodiversité et l'utilisation durable des ressources naturelles de notre planète reste un sujet d'actualité. Dans ce contexte, l'objectif de cette thèse a été d'étudier les effets d'une exploitation forestière sur la qualité écologique de l'eau des rivières, en milieu tropical. L'étude a été considérée à deux échelles, à celle du paysage (bassin versant) et à celle de l'habitat (rivière). Le terrain d'étude d'environ 85 km^2 était situé en Indonésie, sur l'île de Bornéo dans la province de Kalimantan Est, dans le périmètre d'une exploitation forestière de coupe dite "sélective".

L'étude de l'impact des exploitations forestières a été étudié à l'échelle du paysage à l'aide de 5 images satellites (1991, 1997, 1999, 2000 et 2001). La qualité écologique de l'eau des rivières a été évaluée à la fois par des relevés de l'habitat (variables environementales) et de la composition biologique (macroinvertebrés benthiques) de chaque tronçon de rivière considéré. Ces relevés ont été effectués à 23 sites d'échantillonages sur des rivières en tête de bassin. Ceci a permis de comparer des sites de références avec des sites exploités à différentes dates. Plusieurs dates sont considérées: durant l'exploitation et les 6 mois qui suivirent, 1 à 3 ans après exploitation, 4 à 5 ans après exploitation, et après une ré-exploitation des mêmes sites. Deux campagnes d'échantillonnage ont pu être effectuées en Juin-Août 2000 et Avril-Mai 2001. Pendant ces 8 mois d'intervalle, une partie de la concession a été réexploitée suite au processus de décentralisation politique.

Cette recherche, menée pendant quatre ans, a permis d'obtenir les résultats suivants. Les exploitations forestières ont été quantifiées à l'échelle du paysage par la longueur totale des routes d'exploitation. Ceci a mis en évidence l'intensification de l'exploitation au cours du temps (de 1991 à 2001). La classification de la végétation et l'indice de végétation (NDVI) n'ont pu être utilisés pour évaluer les impacts de l'exploitation forestière sur la qualité de la forêt à cause de l'homogénéité du couvert forestier.

Les macroinvertébrés benthiques et les variables environnementales ont permis d'évaluer la qualité écologique de l'eau des rivières dans les sites étudiés. Avec 115 taxa identifiés au niveau de la famille et de la sous-famille (au niveau du genre pour les éphémères), la richesse est élevé, mais l'abondance est faible avec une densité moyenne de 770 individus au mètres carré (entre 86 et 2130 individus). Les analyses multivariées ont permis de mettre en évidence l'importance de la taille des rivières, mais également de distinguer les différentes dates d'exploitation. Une analyse en co-inertie montre qu'il existe une bonne corrélation entre les variables environnementales et la composition des macroinvertébrés benthiques. Les résultats confirment que la densité, les indices de diversité, la composition des macroinvertébrés et des modes d'alimentation sont modifiés après les exploitations forestières. Pendant et 6 mois après exploitation, la densité était supérieure et les indices de diversité inférieurs à ceux relevé dans les sites de référence (non exploité). La situation la plus perturbée correspond à celle relevée un à trois ans après exploitation, indiquée, entre autre par des indices de diversité encore inférieurs à la situation précédente. Les variables environnementales répondent elles aussi aux exploitations, par une augmentation de l'ouverture de la canopée, de la température de l'eau, de la quantité en sédiment fins et de la vitesse du courrant accompagnée par une diminution des matières organiques fines. L'écosystème rivière semble récupérer 4 à 5 ans après exploitation en l'absence de toute perturbation, la densité et la diversité étant similaire alors que la composition en macroinvertébrés est différente de la situation de référence (non exploitée). Parmi les 115 taxa récoltés, certains ont été identifiés comme indicateur des perturbations du milieu engendrés par l'exploitation. Ces indicateurs ont été regroupé en cinq catégories: taxa "canopée ouverte" (*Platybaetis*, Lepidoptera, Hydropsychinae); taxa "sensibles" (p.ex. *Caenodes*, Limonidae, *Potamanthus*, Perlidae, Philopotamidae); taxa "pulsés" (p.ex. Psephenidae, *Jubabaetis*, *Platybaetis*, Megaloptera, Glossossomatidae); taxa "récupère" (p. ex. *Labiobaetis*, Helicopsychidae, Platystictidae) et taxa «adaptatifs» (Diplectroninae, Simuliidae, *Isca*).

Un concept s'appliquant aux rivières tropicales (Tropical Stream Concept) a été proposé en tenant compte de la faible abondance des broyeurs détritivores en tête de bassin. Le taux de décomposition plus élevé et la présence des broyeurs détritivores terrestres permettraient d'expliquer la présence des fines particules de matière organique dans l'eau, provenant directement du lessivage du bassin versant suite aux pluies.

En résumé, les macroinvertébrés sont considérés comme de bons indicateurs de la qualité écologique en milieu tropical et remplissent les deux objectifs posés: ils permettent d'évaluer la biodiversité comme élément de gestion durable des forêts et les impacts des exploitations forestières. La prochaine étape serait de tester les taxa indicateurs dans d'autres sites à Bornéo, de les valider et de préparer une clé d'identification simplifiée à l'usage des institutions locales, comme outil de suivi à long terme de la qualité écologique de l'eau des rivières.

CHAPTER 1

Background and objectives

There is widespread agreement throughout the world from government, industry and the public that the conservation of forest biodiversity and sustainable use of forests are important (Welsch & Venier, 1996). One of the main objectives of global sustainability is the maintenance of biodiversity (Gilliam & Roberts, 1995).

A common definition of **sustainable forest management** was laid down in Resolution H1 (Helsinki Process, 1993) as "the stewardship and use of forests and forest lands in a way, and at a rate, that maintains their biodiversity, productivity, regeneration capacity, vitality and their potential to fulfil now and in the future, relevant ecological, economic and social functions, at local, national, and global levels, and that does not cause damage to other ecosystems".

"**Biological diversity** means the variability among living organisms from all sources including, i.a., terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems" (Convention on Biological Diversity, 1992).

But, biodiversity, encompassing this entire range of ecosystems, habitats, species and genes, is so complex that it is virtually impossible to measure (Noss, 1990). Certain taxa are therefore chosen as "indicator groups" assumed to be representative of total biodiversity (Lindenmayer et al., 2000). One of the key issues identified by the SBSTTA (Subsidiary Body on Scientific, Technical and Technological Advice) is the need for a scientific foundation necessary to advance elaboration and implementation of criteria and indicators for forest quality and biodiversity conservation.

Criteria and indicators are tools for assessing trends in forest condition and forest management. "**Criteria**" define the essential components of sustainable forest management. These include vital forest functions; biological diversity and forest health; multiple socio-economic benefits of forests, such as wood production and cultural values; and, in most cases, the legal and institutional framework needed to facilitate sustainable forest management. Associated "**indicators**" are used to define what a criterion is and to measure it. Measured over time, indicators can demonstrate

trends toward or away from sustainable forest management, giving policy-makers the necessary information to implement corrective action. These concepts and the terminology associated with Criteria and Indicators (C & I) were introduced by the ITTO (International Tropical Timber Organisation) in 1992 (ITTO, 1992a). Since then, seven other "processes" have been developed in different parts of the world. In June 1993, 38 European countries adopted the Helsinki Process. This was followed a few months later by 12 non-European temperate countries which established the Montreal Process. In 1995, eight countries in the Amazonian Cooperation Treaty began to formulate the Tarapoto Proposal, identifying C & I for the Amazon forest and since then, 27 sub-Saharan countries have been developing C & I for Dry Zone Africa, while similar work has been undertaken in the Near East and Central American regions. The latest addition is the C & I of the African Timber Organisation for African natural forests (ATO/ITTO, 2003).

As part of these C & I processes, the **aim** of this research is **to study the effects of logging activities on ecological water quality indicators in a tropical forest.** The study was undertaken at both local (species/habitat) and landscape (watershed) scales.

The study area was located in Indonesia, in East Kalimantan Province on Borneo Island. A collaboration with CIFOR (Centre for International Forestry Research) was build. They were conducting research in forestry inside a state-owned timber concession. This area presented several interesting features: at the time the present study began, the concession was mostly covered by primary unlogged tropical lowland Dipterocarps forest, which allowed to find streams that could act as reference sites; main activity was logging which enabled to focus on one type of disturbance, avoiding combining impacts such as grazing, agriculture, plantations, fires, villages; local population still relied on streams for domestic uses, such as drinking water, bathing, fishing,... On the other hand, the proposed infrastructure was poor due to difficult access, information on the area was scarce (geology, rainfall, contour map, river map,..) and aquatic fauna poorly known.

Within this framework, the following **research objectives** became:

- **to assess logging activities in a tropical forest at landscape scale (watershed)** presented in chapter 5
- **to study the relationships between stream habitat (environmental variables) and its fauna (benthic macroinvertebrates community), as indicators of ecological water quality in a tropical forest**, presented in chapter 6
- **to study the effects of logging activities on ecological water quality at local scale (species/habitat)**, presented in chapter 7

Because of its importance for local population for domestic use, ecological water quality was selected from a whole range of existing indicators as part of sustainable forest management. **Water quality** is usually defined according to its use, such as preservation of aquatic life, drinking water, agriculture, fishery, industry and recreation. "**Ecological water quality**" used in this study is defined as "the capacity for the water to maintain and sustain aquatic life". It is described by physico-chemical characteristics (pH, temperature, turbidity, etc.) and biological components (periphyton, macroinvertebrates, fishes, etc.) (Rodier, 1984). Therefore, a habitat quality assessment and a biological assessment was performed in the study area. An evaluation of **habitat quality** as part of any assessment of ecological integrity was performed at each site at the same time as the biological sampling. Here, the definition of "habitat" is narrowed to the quality of the instream and riparian habitat that influences the structure and function of the aquatic community in a stream. **The biological composition** of streams is thought to reflect ambient conditions and integrate the influence of water quality and habitat degradation (Lammert & Allan, 1999). Macroinvertebrates were chosen for this study because of their characteristics mentioned below.

Benthic macroinvertebrates are defined as all organisms with size more than 1 mm living on the bottom of the rivers, on or inside the substratum. Insects constitute the majority of benthic macroinvertebrates in rivers and include the Ephemeroptera (mayflies), Plecoptera (stoneflies), Trichoptera (caddisflies), Coleoptera (beetles), Diptera (true flies), Lepidoptera (moths), Odonata (damselflies and dragonflies), but as well Decapoda (shrimps and crabs), Gasteropoda (snails), Turbellaria (worms) and others.

Benthic macroinvertebrates have the following characteristics: as a community, they have high diversity and abundance, high lifeform diversity which means highly sensitive response to environmental changes; as individuals, they have a restricted mobility and thus reflect their habitat. Plafkin et al. (1989) suggested that macroinvertebrates are more indicative of local habitat conditions while fishes reflect conditions over broader spatial areas because of their relative mobility and longevity; short life cycle and relative easy identification (when appropriate identification keys are available). Sampling methods, as well as statistical data analysis and interpretation are broadly used and well established.

Many studies using macroinvertebrates as indicator have been conducted, such as influence of land use on habitat quality and biotic integrity (Hawkins et al., 1982; Robinson & Rushforth, 1987; Townsend et al., 1997) in examining the effect of agriculture (Neumann & Dudgeon, 2002), in monitoring long-term recovery from clear cut logging (Stone & Wallace, 1998; Growns & Davis, 1991) or from wildfire (Minshall et al., 2001). Several countries, such as Australia (AUSRIVAS, Smith et al., 1999), the United states (ICI, Invertebrate Community Index, DeShon, 1995), United Kingdom (BMWP scoring system, Hawkes, 1997), France (IBGN, Indice Biologique Global Normalisé, AFNOR, 1992), Switzerland (RIVAUD, Lang & Reymond, 1995) and others countries currently use macroinvertebrates as a measure of biological integrity in rivers and streams.

The **results** obtained during this study should improve the ability to evaluate the forest "quality" by evaluating the effects of logging activities on the benthic macroinvertebrates in forest streams and thus, to contribute to management decision for sustainable use of tropical forests. According to Chiasson (2000), the Canadian Council of Forestry Ministers cited water quality not only as indicator of biological integrity in rivers and streams, but as well as an indicator of sustainable forestry practice. Results should also contribute to increase the knowledge in tropical aquatic ecosystems, as very little is known about the ecology of tropical freshwater in general, and tropical asian rivers and streams in particular (Dudgeon, 1999). Indicators should provide information to forest managers and policy makers which is relevant, scientifically sound and cost-effective.

The rationale for **relating ecological water quality of streams and forest quality** is that streams are a reflection of the watersheds they drain (Hynes, 1975). The climate, geology, and soil of an area determine the substratum, seasonal discharge, channel morphology, and chemical properties of the waterbody. Vegetation has strong influence on the headwaters of rivers where instream primary production is low because of shading, but where the vegetation provides large amounts of allochtonous detritus. These inputs influence the structure and functional organisation of the biotic stream community, such as fish and macroinvertebrates (River Continuum Concept, Vannote et al., 1980). The vegetation type and its extent also influence water quantity as well as its temperature and clarity (Bryce & Clarke, 1996). Therefore, the study focused on the catchment headwater (third to fourth stream order), because, according to Church (1994), it is a reasonable generalisation that the impacts of land use occur most severely upon smaller, headwater channels.

This led to a **multi-scale approach** intending to study the relationship between the two levels of assessment: from landscape (watershed) to local (species/habitat) scale. Indeed, in recent studies, several authors emphasise the importance of using a variety of spatial scales to measure biodiversity (Duelli, 1997; Haila & Kouki, 1994; Noss, 1990; Thompson et al., 1996). The importance of spatial scale has attracted much interest within the field of ecology, both on theoretical grounds (Forman & Godron, 1986; Turner, 1989;

Levin, 1992) and from the growing conviction that habitat fragmentation at the landscape scale is an important and previously unappreciated causal agent in species decline (Noss, 1990). River systems may prove to be especially suitable systems for the investigation of ecological processes across spatial scales.

The dissertation is structured in the following way: chapter two, “State of the Art” presents some of the existing concepts of landscape, river ecology and disturbances. Some general information is given on the political situation in Indonesia and in the forestry sector. Literature on landscape, ecological water quality and logging activities in Indonesia is reviewed. Chapter three presents the “Study Area” located in the state-owned Inhutani II timber concession with its natural and social features, as well as description of the management of the forest inside this timber concession. “Materials and methods” are described in chapter four including the sampling strategy, measured variables, landscape and ecological water quality methods used, as well as the data analysis. Chapter five presents the results obtained on the assessment of the logging activities at the landscape scale (watershed). Chapter six presents the results on the study of the relationships between environmental variables and benthic macroinvertebrates and the chapter seven presents the effects of the logging activities on the ecological water quality. The results are discussed in chapter eight. Chapter nine presents the outcome and limitation of the study, as well as some ideas for further research.

CHAPTER 2

State of the Art

This chapter has two main objectives. The first is to discuss some of the existing concepts of landscape and of river ecology. Particular attention is paid to ecological disturbance concepts, because of the focus on impact of logging activities. The second objective is to review existing literature and information relevant to the study in Indonesia, including an overview of the Indonesian political situation and forestry management system.

2.1 Landscape ecology concepts

In the Bulletin of the International Association for Landscape Ecology (1998) the following definition was proposed: "Landscape ecology is the study of spatial variation in landscapes at a variety of scales. It includes the biophysical and societal causes and consequences of landscape heterogeneity. Above all, it is broadly interdisciplinary". Another simpler definition offered by Pickett & Cadenasso (1995) is "the study of the reciprocal effects of spatial pattern and ecological processes".

Hierarchy theory suggests that in any study, it is important to include both large-scale phenomena to understand the context, and fine-scale dynamics to examine mechanisms (O'Neill et al., 1986). In this study, watershed was studied at the landscape scale and macroinvertebrate taxa at the local scale, in order to study the diversity of the benthic macroinvertebrates community. According to Fisher et al. (1998), streams are important landscape elements that process materials derived from terrestrial catchments and greatly affect the nature of inputs to downstream lakes, reservoirs, estuaries, flood plains, and groundwater.

A **landscape** is a mosaic where the mix of local ecosystems or land uses is repeated in similar form over a kilometres-wide area (Forman & Godron, 1986), with heterogeneity among ecosystems or land uses significantly affecting biotic and abiotic processes in the landscape (Turner, 1989). There is empirical justification for man-

aging entire landscape, not just individual habitat types, in order to ensure that diversity is maintained (Noss, 1990).

The stream order classification of geomorphologists provides a valuable framework for investigation of the hierarchical organisation of river networks. Stream ecologists also recognise a hierarchical organisation of micro-habitats such as gravel, wood or leaf detritus, within larger habitat units such as riffles or pools, which in turn comprise a stream reach. A reach is contained within a river segment, which is part of the catchment of a single tributary stream, and often is part of a larger river basin made up of many such tributaries (fig 1) (Allan et al., 1997).

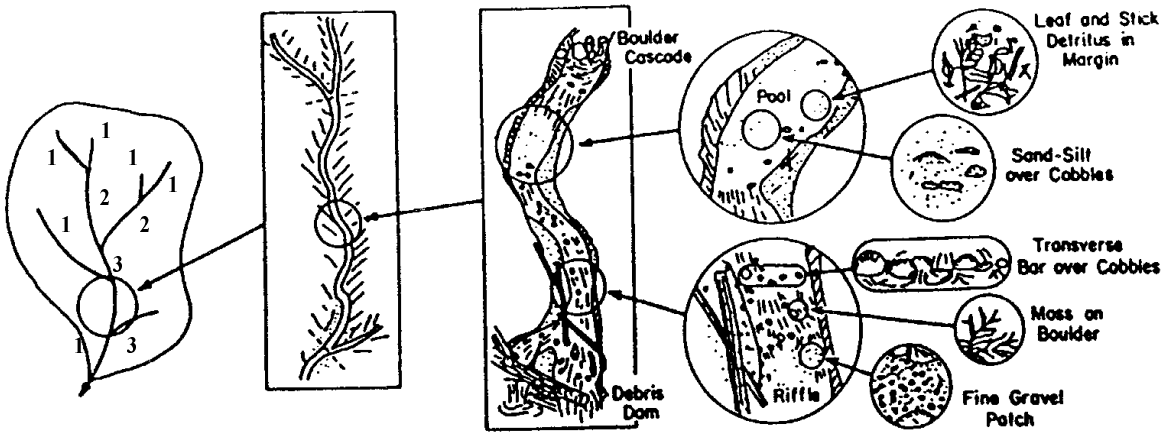


FIGURE 1. **Landscape influences on stream ecosystem structure and function across spatial scale. Hierarchical relationships among habitat and landscape features of streams. Multiple micro habitat units are found within each channel unit such as pool or riffle; multiple riffle/pool units comprise a stream reach; reaches are contained within river segments, which are part of a catchment, which often is a tributary within a large river basin. Stream order is defined according to Horton (1945). Figure from (Frissel et al., 1986) as cited by Allan & Johnson (1997).**

This study examines the following spatial scales: the catchment, the reach and the habitat units (channel units). They are defined thereafter.

The **catchment**, according to Forman (1995) is the area bounded by topographic divides that drains into a river system. A landscape view of a catchment (river) basin encompasses the entire stream network, including interconnection with groundwater flow pathways, embedded in its terrestrial setting and flowing from the highest elevation in the catchment to the point of confluence with another catchment system or with the ocean (Allan et al., 1997).

Reaches consist of relatively homogeneous associations of topographic features and channel geomorphic units, which distinguish them in certain aspects from adjoining reaches. Transition zones between adjacent

reaches may be gradual or sudden, and exact upstream and downstream reach boundaries may be a matter of some judgement (Hauer & Lamberti, 1996).

Channel units or **habitat types** are relatively homogeneous areas of the channel that differ from adjoining areas of streams in depth, velocity, and substrata characteristics. The most generally used channel unit terms for small to mid-sized streams are riffles and pools. Definitions of channel units usually apply to conditions at low discharge (Hauer & Lamberti, 1996).

2.2 River ecology concepts

During the past several decades, river ecosystem concepts have been developed to describe the functioning and structure of natural, undisturbed rivers (Lorenz et al., 1997). Many descriptive studies of biological communities in small streams (e.g. Minshall, 1981; Cummins et al., 1995) and more holistic concepts recognised that stream biota were influenced by the surrounding landscape (e.g. Vannote et al., 1980; Allan et al., 1997). As this study focused on headwater streams, only related concepts are summarised thereafter.

2.2.1 River Continuum Concept

The development of the River Continuum Concept (RCC) by Vannote et al. (1980) was an important step in river ecology, as it was the first attempt to describe both the structural and functional characteristics of stream communities along the entire length of a river. This concept was developed specifically in reference to naturally undisturbed river ecosystems in North America. The RCC (see figure 2) argues that the biotic stream community adapts its structural and functional characteristics to the abiotic environment, which presents a continuous gradient, from headwater to river mouth. This is expressed by the source and distribution of organic matter and macroinvertebrate functional feeding groups.

In general, rivers can be divided into three parts based on stream size: headwaters (stream order 1-3), medium-sized streams (order 4-6) and large rivers (order > 6). The headwaters of rivers are strongly influenced by riparian vegetation. Primary production in the headwaters is low because of shading, but the vegetation provides large amounts of allochtonous detritus. Thus, the ratio of gross primary Productivity (P) to Respiration (R) of the aquatic community is small (P/R<1). The size of the particulate organic matter is rather large, consisting mainly of dead leaves and woody debris (coarse particulate organic matter CPOM> 1mm).

The influence of riparian zone diminishes moving downstream: both the importance of terrestrial organic input and the degree of shading decreases, whereas primary production (from P/R<1 to P/R>1) and transport of organic matter from upstream increases. The size of organic matter decreases to fine particulate organic matter (FPOM < 1mm). Large rivers receive organic matter, mainly from upstream, which has already been processed to a small size. Primary production is often limited by depth and turbidity, so the P/R ratio decreases again (P/R< 1).

Changes in the size of organic matter along the length of the river are reflected in the distribution of functional feeding groups of invertebrates. In the headwaters, the influence of riparian vegetation, through shading and litter inputs, is expressed in the general heterotrophic nature of such areas (Cummins et al., 1995). Litter of terrestrial origin favours shredders which process CPOM. They are codominant with collectors, which obtain their food by filtering it out of the water or gathering from the sediment FPOM, which has been processed from CPOM by shredders. The exclusion of light by riparian vegetation restricts in-stream primary production and consequently also limits the periphyton-grazing scrapers. Collectors and

grazers-scrapers, which shear attached algae from surfaces, dominate the middle part of the reach, where light increases. In the lower reaches, the invertebrate assemblage consists mainly of collectors. There is a fairly constant relative abundance (approximately 10%) of predators in all reaches.

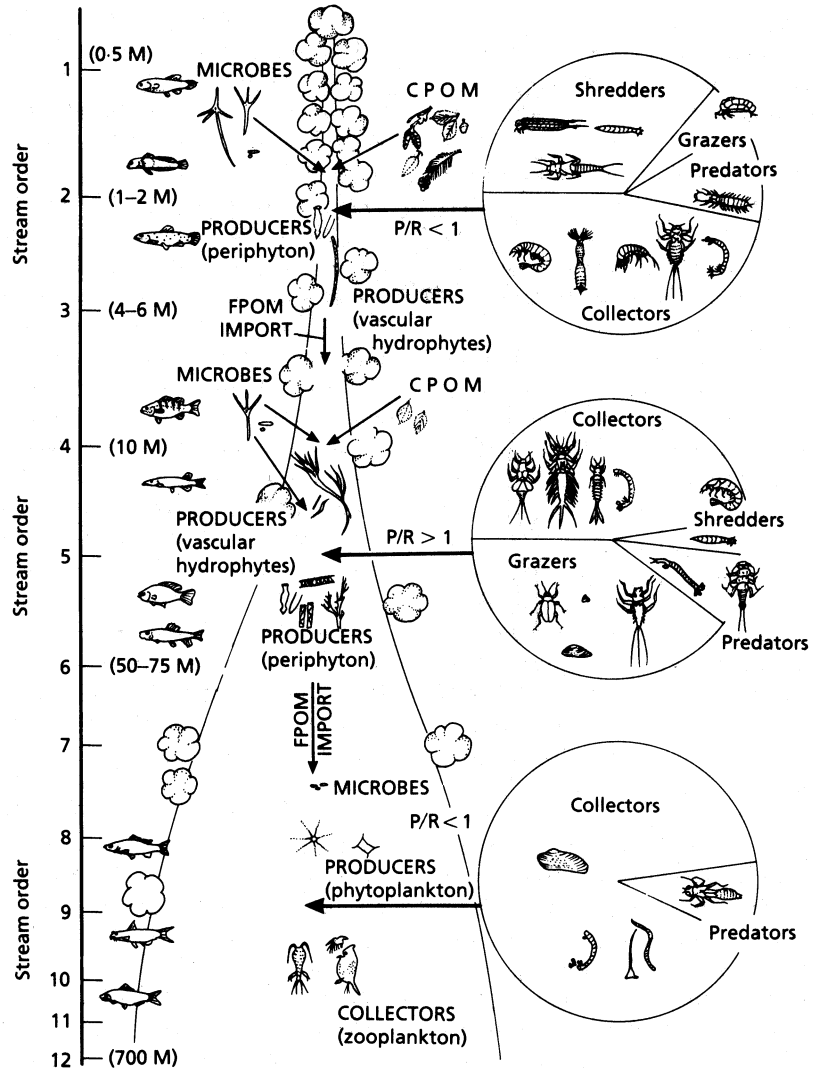


FIGURE 2. A generalised model of the shifts in the relative abundances of invertebrate functional feeding groups along a river tributary system from headwaters to mouth as predicted by the river continuum concept (RCC, Vannote et al., 1980).

The RCC concept provides a framework for understanding the ecology of streams and rivers and is not intended as a description of the biological components of all rivers individually. Reservations have been expressed about the applicability of the RCC to different river systems. These limitations are mainly because 1) the RCC was developed on small temperate streams, but has been extrapolated to rivers in general and 2) it was based on a concept that had been elaborated for the river basin in a geomorphological sense but was in fact restricted to habitats that are permanent and lotic. However, large floodplain rivers are significantly influenced by regular floods of the main stream into the bordering floodplains. The flood

pulse concept of Junk et al. (1989) described the effects of floods on both the river channel and its flood plain, as well as on the biota that have adapted to this system. Their concept is mainly based on large river-floodplain, relatively pristine systems in the neotropics, Southeast Asia and Upper Mississippi River. Other reservations have been made about the RCC applicability to different regions. For example, a shredder paucity had been mentioned in several studies in Southeast Asia, Hong Kong, New Guinea (Dudgeon et al., 1994; Dudgeon, 1999; Yule, 1996b), in New Zealand and Australian streams (e.g. Winterbourn et al., 1981; Marchant et al., 1985), Central America (Pringle & Ramirez, 1998) and in Kenya (Dobson et al., 2002).

2.2.2 The longitudinal gradient or stream hydraulic concept

The all-important feature of river ecosystems for the biota they contain and the ecosystem processes that occur within them, is that they flow in one direction, by gravity, from source to sea. This theory (Statzner & Higler, 1986) distinguishes a zonation pattern of benthic fauna in which the distinct changes in species assemblage are often linked to transition in stream hydraulics.

Stream hydraulics are determined by the geomorphological and hydrological characteristics of the river, such as flow velocity, depth, substrate roughness and surface slope (see fig. 3). These determine local conditions which in turn influence local community structures and ecosystems processes (Petts & Calow, 1996b).

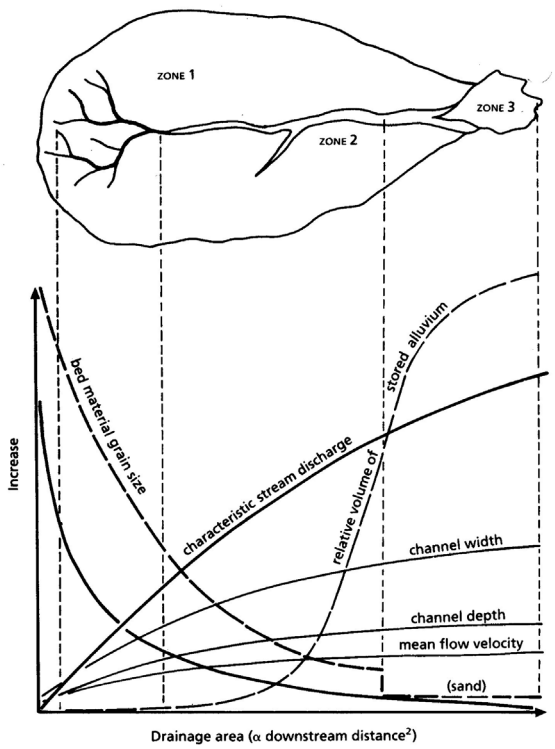


FIGURE 3. **Schematic representation of the variation in channel properties through a drainage basin (based on a concept of Schumm 1977 in (Petts & Calow, 1996b).**

2.2.3 The four-dimensional nature of lotic ecosystems

The four-dimensional concept presented by Ward (1989) is mentioned here as it introduced the temporal scale. Upstream-downstream interactions constitute the longitudinal dimension, as expressed by the longitudinal gradient or the RCC. The lateral dimension includes interactions between the channel and riparian/ flood plain systems, which is more related to large river and does not concern the studied headwater system. Significant interactions also occur between the channel and contiguous groundwater, the vertical dimension through the hyporheic zone (sub-benthic habitat of interstitial spaces between substrate particles in the stream bed). The fourth dimension, time, provides the temporal scale. Lotic ecosystems have developed in response to dynamic patterns and processes occurring along these four dimensions.

2.3 Disturbance concept

Disturbance is regarded by many stream ecologists as playing a central role in determining the structure of stream communities (e.g. Resh & Rosenberg, 1989; Lake, 2000). Disturbance is defined by (Stanford & Ward, 1983) as: "any stochastic event which forces normal system environmental conditions substantially away from the mean". Severity of disturbance includes both frequency (or timing) and duration.

For Lake (2000), perturbation describes the combination of cause and effect: disturbance becomes the cause of a perturbation, and response becomes the effect of the disturbance. Disturbances may be characterised by their temporal patterns: thus, we have pulses, presses and ramps (see fig. 4). **Pulses** are short-term and sharply delineated disturbances (e.g. floods). **Presses** may arise sharply and then reach a constant level that is maintained (e.g. sedimentation after landslides or after fires), mostly resulting of human activities (e.g. dams, channelisation, heavy metal pollutants). **Ramps** occur when the strength of a disturbance steadily increases over time (droughts as "creeping disaster", increasing sedimentation of a stream as its catchment is cleared, or the incremental spread of an exotic organism).

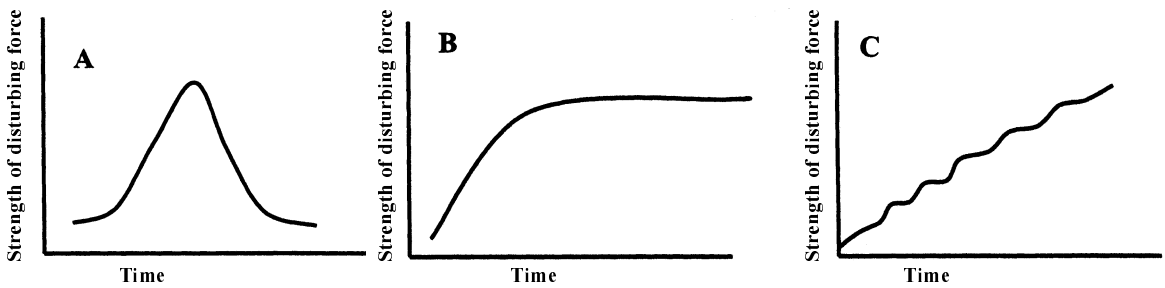


FIGURE 4. **Three types of stream disturbance (A: Pulse, B: press, C: ramp) distinguished by temporal trends in the strength of the disturbing force. Note that ramp disturbances may level off or increase steadily throughout the period of observation (Lake, 2000)**

The response of the system has often been confounded with the disturbance itself. It can also take the form of pulse, press or ramp response. The characterisation of the response is linked with the qualities of **resistance**, a measure of the capacity of the system to withstand a disturbance, and **resilience**, a measure of the capacity of the system to recover from disturbance.

A number of hypotheses have been proposed to explain how disturbance affects diversity. One of these hypothesis was developed by (Connell, 1978), as the "Intermediate Disturbance Hypothesis". This hypoth-

esis suggested that highest diversity is maintained at intermediate scales of disturbance (figure 5) and is a consequence of continually changing conditions. This theory was proposed for plants (tropical rainforests) and sessile animals (coral reefs). The hypothesis is based on the argument that ecological communities seldom reach an equilibrium state, in which the competitively superior individuals will continually set back the process of competitive elimination by opening space for colonisation by less competitive individuals.

(Connell, 1978) concluded by underlining that "although tropical rain forests and coral reefs require disturbances to maintain high species diversity, it is important to emphasize that adaptation to these natural disturbances developed over a long evolutionary period".

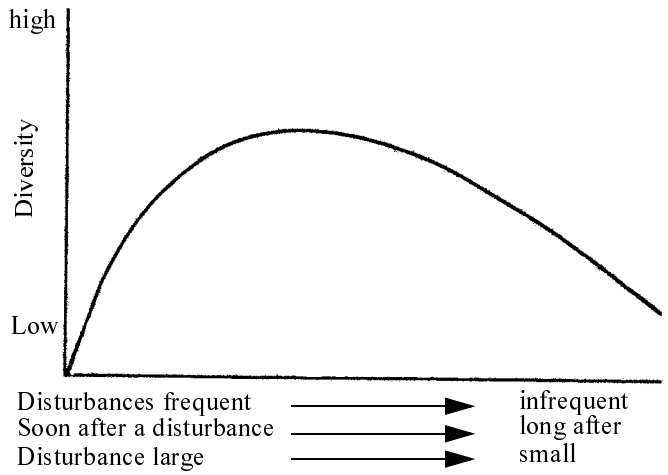


FIGURE 5. **The Intermediate Disturbance Hypothesis (Connell, 1978).**

The Intermediate Disturbance Hypothesis has been studied in stream ecology, disturbance regarded as playing a central role in determining the structure of stream communities (e.g. Lake, 2000; Matthaei & Townsend, 2000; Palmer et al., 1992; Reice, 1985; Resh et al., 1988; Robinson & Rushforth, 1987; Stanford & Ward, 1983). It also has important practical implications for the maintenance of biodiversity, of which species richness is the most basic component (Townsend & Scarsbrook, 1997). It appears that intermediate level of disturbance induced by the flooding regime may lead to higher levels of alpha and beta diversity (Ward, 1998). However, according to Death (2002), there appears to be no widely accepted model that can be used to predict link between diversity and disturbance, nor is there much understanding of the mechanisms behind that relationship.

2.3.1 Documented impacts of logging activities in South-East Asian tropical forests

As the impacts of logging activities have been the subjects of a pletoria of studies, studies mentioned thereafter are focused on South-East Asian tropical forests.

In Borneo, primary lowland forests exhibit a high density of harvestable trees (23 trees/ha > 50 cm diameter and 16 trees/ha >60 cm diameter) (Sist & Nguyen-Thé, 2002). As a result, these forests are considered as highly productive compared to other countries (table 1) and harvesting intensity commonly exceed 100 m3/ha representing more than 10 trees/ha (Sist et al., 2002). In Africa and South America, harvested volumes generally remain below 50 m3/ha (Sist et al., 1998).

There have been several studies on the effects of logging in southeast Asian rainforests focusing mainly on the amount and types of damage sustained by the residual stand immediately after logging, and the degree to which the forest floor was disturbed by roads and tracks (e.g. Nicholson, 1958; Fox, 1968; Tinal and Palenewen, 1978; Abdulhadi et al., 1981; Borhan et al. 1990; as cited by Cannon et al., 1994). These studies revealed that, as everywhere in the tropics --but mainly in Southeast Asia and in South America-- apart from exceptions, logging of natural forest is rarely sustainable.

TABLE 1. Harvesting intensity in some tropical countries.

Countries	No. of trees per ha (m^3/ha)	References
Brazil	4 to 8	Barreto et al., 1998; Johns et al., 1996; ; Winkler, 1997 as cited by Boltz et al., 2003; Holmes et al., 2002
Ecuador (northwest)	8	Montenegro, 1996 as cited by Boltz et al., 2003
Guyana	3 to 16	Armstrong, 2000; Van der Hout, 1999: as cited Boltz et al., 2003
Bolivia (Santa Cruz)	4.32 (12.1)	Jackson et al., 2002
Indonesia	> 10	Dykstra and Heinrich, 1996; Bertault & Sist, 1997; Sist et al., 2002

Loss of biodiversity and **loss of structure of** residual **stands**. The unlogged lowland forest is species-rich, but the commercial species dominate, comprising 70% of total precut basal area. Cannon et al. (1998), in a study in West Kalimantan (Indonesian Borneo), found that, by removing 62% of dipterocarps basal area and 43% overall, logging reduced both tree density and the number of tree species per ha, for both large and small trees. For all trees > 20 cm in diameter, density fell by 41% and the number of species per plot by 31%. The percentage of lowland forest classed as moderately to heavily disturbed ranged from 70 to 84%. Other studies of residual stand include Haeruman (1978); Rosalina (1986); Tinal and Palenewen (1978); Abdulhadi et al. (1981); as cited by Cannon et al. (1994).

Logging activities, apart from log cutting and felling, include all associated infrastructure such as skid trails, roads, river landings, etc., which imply major movements of soils. These infrastructure elements can be major factors of **soil erosion** if improperly constructed or maintain. In Indonesia, there is ample evidence that typical timber concession apply poor road construction, maintenance and drainage practices. Additionally, inadequate planning and layout of logging blocks with excessive amounts of improperly designed skid trails are frequent (Klassen, 1999; Sève, 1999; pers. observ.). Erosion can also inflict direct damage to infrastructure such as roads and bridges, and human settlements in the form of mud flows and flooding. The life span of hydroelectric and irrigation dams can be considerably reduced as a result of erosion (Sève, 1999).

Impact of logging on rivers and macroinvertebrates. Since 1980, many studies have been carried out on logging or forest conversion effects on hydrology and sediment yield in Malaysia (Zulkifli et al., 1990; Lai, 1992; Malmer, 1990; Law et al., 1989: as cited by Douglas et al., 1993; Douglas et al., 1992). Logging and ground clearance increased river sediment by two to fifty times in Danum Valley (North Borneo) (Chappell et al., 1999). Soil erosion can have an impact on water quality, primarily through suspended solids, but also by increasing biochemical oxygen demand (BOD), all of which can affect downstream users of drinking water (Sève, 1999). Seasonal flow patterns can also be affected as a result of altering the vegetative cover of watersheds.

In temperate climate, deposited sediment affected the structure and function of benthic macroinvertebrates communities by increasing substrate embeddedness and altering substrate particle-size distribution (Culp et al., 1983; Erman & Erman, 1984; Minshall, 1984; Lenat et al., 1981), producing a reduction in habitat

quantity and quality. A small increase in sediment may reduce macroinvertebrate population densities because of a reduction in habitat space; however, community structure may not change. Alternatively, as deposited sediment increases, densities may increase, and alterations in community structure and diversity can occur. Zweig & Rabeni (2001) underlined that changes in macroinvertebrate fauna caused by deposited sediment were difficult to isolate and quantify because they often accompany other changes in the stream, such as removal of riparian vegetation, alterations in flow and temperature regimes and nutrient enrichment.

But for Borneo, there is a lack of data on most lowland rivers to ascertain whether the rapid expansion of logging has caused channel changes which could potentially affect the lives of the riparian communities, including the macroinvertebrates (Douglas et al., 1993). Martin-Smith et al. (1999) studied the mechanisms of maintenance of tropical freshwater fish communities in the face of selective logging activities in Danum Valley (Sabah, Malaysia). They found that fish communities from headwater streams showed few long-term changes in species composition or abundance, but short-term (<18 months) absence of decrease in abundance.

Evidence suggests that in tropical rainforest environments, selective logging may lead to an increased susceptibility of forests to **fire**. Siegert & Hoffmann (2000) assessed the extent of the fire-damaged area and the effect on vegetation in East Kalimantan following the 1997-98 fires associated with El Niño phenomenon. A total of 5.2 +/- 0.3 million hectares including 2.6 million ha of forest was burned. Forest fires primarily affected recently logged forests; primary forests or those logged long ago were less affected.

Human impact by road construction and logging, as well as man-made fires has accelerated the **fragmentation** in various vegetation types. A study on the effect of fragmentation on the behaviour of Bornean gibbons emphasizes that the fragmentation of habitats causes a slow, but sure, increase in the number of species facing extinction through a decrease in genetic diversity that enables adaptation to environmental change, although the effects are not apparent immediately (Oka et al., 2000).

As a result of these poor logging practises, **Reduced Impact Logging (RIL)** has been developed. Previous studies of RIL in Southeast Asia have demonstrated that damage to the tropical forests can be significantly reduced by applying simple techniques of forest management planning, including pre-harvesting surveys, pre-mapping of timber trees, vine cutting, design and location of skid trails before logging and directional felling. Although most current harvesting system throughout South-East Asia encompasses almost all these RIL rules, they have not been applied on a larger scale for numerous reasons. These include lack of technical knowledge, minimal control of harvesting practices and the perceived high economic cost of RIL.

2.4 Review of existing literature and information on Indonesia related to the study

2.4.1 Politics and Forestry in Indonesia

Indonesia's territory today is defined by the boundaries of the former Dutch East Indies, as a result of Dutch colonisation which began in 1602. In 1942 the Japanese conquered the Dutch East Indies, and after Japan's defeat Indonesian nationalists under the leadership of Sukarno declared independence in August of 1945. Sukarno became President and a 15 year period of political instability and economic decline followed, during which there were numerous verbal conflicts with the Netherlands and a military conflict with Malaysia. In 1965 a failed coup d'état led by a group of military officers occurred with the support of

the Indonesian Communist Party and China. The coup was crushed and as many as 750,000 of the supporters of the communist party were killed. The coup marked the end of Sukarno's presidency and in March 1966 a "New Order" was established. In March 1968, Suharto became president. When the New Order was established, the government defined three economic objectives: stability, growth and equity, to be achieved through a series of 5-year development plans (REPELITA), applicable to the public and private sector. The results were successful in several ways and the economy grew at an average rate of 6.8% from 1965 to 1995 and became increasingly export-orientated. In 1995, oil and gas accounted for 23% of exports by value, followed by timber products (10%) and textiles (6%). Poverty declined since the 1960s but substantial inequalities of income remain, as well as widespread corruption.

A regional economic crisis in Southeast Asia which began in 1997 had major political and economic impacts on the country. In May 1998, President Suharto resigned and was replaced by his Vice-President Mr. Habibie. In mid-1998, 50 million Indonesians were living in poverty largely due to price increases as a consequence of the decline in the value of the rupiah (80% of it value). During parliamentary elections in 1999, Megawati Sukarnoputri's party won must of the votes, a third of the total, in a race between dozens of parties. But Muslim cleric Abdurrahman Wahid outmanoeuvred Megawati when legislators chose the president a few months later. Those legislators sacked Wahid for incompetence in July 2001, allowing Megawati to move up from the vice-president's post. She was appointed as Indonesia's fifth president.

Figure 6 summarises the Forestry in Indonesia for the last 30 years. More information on the detailed processes can be found in the following sources: Elliott (2000), a review of Forestry sector policy issues (Sève, 1999) and a guideline concerning the natural production forest management (NRMP, 1993) both supported by the Natural Resources Management program, and a World Bank report (WorldBank, 2001).

2.4.2 Importance of forestry in the Indonesian economy

Forestry in Indonesia has changed rapidly over the last thirty years. Until the late 1960s, commercial timber production was mostly limited to teak plantations in Java. Starting in the early 1970s, large areas of forests in the "outer islands" (especially Kalimantan and Sumatra) were allocated by the government to the private sector in the form of 20-year timber concessions (Elliott, 2000). Indonesia started the 1980s as a log exporter and, because of a ban on log exports (1991-1996) to promote domestic processing, ended the decade as a major plywood exporter. With the growth of the plywood industry, the political and economic influence of the private sector increased. The development of the pulp and paper industry is a current priority with substantial investments being made in plantations and pulp and paper mills, partly encouraged by tax-write-off (Elliott, 2000).

Annual log production increased from 1.4 million cubic metres in 1960 to 33 million in 1996. Log production in East Kalimantan has been about 3-5 million m^3 per year during the past 20 years, which account for about 20% of the entire production in Indonesia. The seventh Development Plan (for the years 2000 to 2004) has set a log production target of 57.2 million m^3 per year for the whole of Indonesia. Although the plan will be reassessed because of the economic crisis in 1997-98, the productive capacity of timber processing mills and upgrading the living standards of the country will require more log production than the present amount of about 25 million m3/year (Fatawi & Mori, 2000).

Until the mid-1990, resource-related exports from the natural forest were an engine of economic growth. Forest-based exports (plywood, furniture, and pulp) rose from around $200 million in the early 1980s to more than $ 9 billion per annum in the mid-1990s. In 1997, total output from forest-related activities was about $20 billion (10% of GDP). Forest-related employment were about 800,000 jobs in the formal sector, and many more than this engaged in activities in the non-traded forest products sector. Royalties and other government revenues from forest operations exceeded $1.1 billion per annum (WorldBank, 2001).

- Constitution and Basic Forestry Law of 1967 stated that State controlled land, water and natural resources
- timber concessions are granted for 20 years, but tree-harvesting cycles are every 35 years => no security of tenure
- a high priority is given to timber production

The reality since the forestry law of 1967

- cartel and monopoly on wood production by Suharto and a few members of his government and family, with centralisation of Ministry of Forestry in Jakarta (Barr, 1998)
- development of hundreds of regulations and decrees

  => directives detailed, but not always consistent with one another

  => high pressure on forest concession who spend their time on administration instead of forest management

As a result

- corruption at all government and local levels
- illegal logging
- unsustainable forest management

Decentralisation as a solution?

Decentralisation started in 1999 with following basic changes in forestry sector:

- all local resources, including forestry activities, are under the supervision of the local government
- local population recover their rights on the uses of their natural resources

But, so far.....

- new forestry laws ambiguous and lack essential implementing guidelines, which lead to confusion with old existing laws
- decentralisation process too rapid, no time to build human capacities at regional government level for land-use planing, forest management, conservation area and the other new tasks
- land ownership to be determined between the local population arise conflicts
- acceleration of environmental degradation (logging activities increase up to 3 times official logging (Casson & Obidzinski, 2002)) to money natural resources, by taking advantages of the lack in government controls

FIGURE 6. **Summary of main characteristics of forestry sector in Indonesia since 1967**

Recent trends in tropical timber production, excluding plantations, show a decrease in the Asian-Pacific region's share of global production by approximately 30% from 1992 through 1999. This decrease can be attributed to the Asian economic crisis which also affected Indonesia's plywood exports to key markets such as South Korea and Japan. The Ministry of Forestry estimated that plywood export revenues in 1997 were 25% lower than in 1996 (Fatawi & Mori, 2000). Production in the Latin America-Caribbean region, which is dominated by South American producers, increased 15.8% over the same period (ITTO in Boltz et al., 2003).

2.4.3 Deforestation and forest degradation

Concerns began to be raised about deforestation and forest degradation in Indonesia by Indonesian NGOs and foreign scientists and observers in the mid-1980's, at a time when international concerns about loss of tropical forests, and the role of the international timber trade in this, were increasing. One of the catalytic events was the large forest fires in Kalimantan in 1982 and 1983.

There has been considerable controversy concerning the causes of deforestation, with analysts divided over the direct and indirect responsibilities of logging, shifting cultivation, land clearing for plantation (both forest and non-forest) and transmigration. Land clearing is performed by various methods of which the use of fire is one of the most important. Approximately, one tenth of the annual rate of deforestation is attributed to logging in natural forests (Sève, 1999). In general, concession operations are characterised by inadequate planning prior to harvesting procedures and systems, poor road location and design, rigid log specifications, and excessive wood residue remaining in the forest following harvesting. These are all factors that contribute to the degradation of forest ecosystems.

In a recent study from Achard et al. (2002), the changes in humid tropical forest cover from satellite remote sensing imagery were estimated. Southeast Asia had the highest annual percentage deforestation rate (0.91%), and Africa lost its forests at about half the rate of Southeast Asia. Latin America showed the lowest percentage rate, but at a rate of 2.5 x 10^6 ha $year^{-1}$, the annual loss of forest area was almost the same as the loss estimated for Southeat Asia (2.5 +/-0.8 x 10^6). These estimates represent only the proportion of degradation identifiable using remote sensing, which does not include processes such as selective logging as well as the fire events in Indonesia in 1997-1998.

TABLE 2. Forest cover, forest loss and logging activities: comparison between the whole country, Kalimantan and East Kalimantan province. Sources from Fatawi & Mori (2000) and WorldBank (2001) report.

	Indonesia		Kalimantan		East Kalimantan	
	1985	1997	1985	1997	1985	1997
Total land area (ha)	190'905'100	189'702'068	53'583'400	53'004'002	19'721'000	19'504'912
Forest area (ha)	119'700'500	100'000'000	39'986'000	31'512'208	17'875'100	13'900'000
Forest %	62.7	50.1	74.6	59.5	90.6	71.3
Forest loss (%)	16.5		21.2		22.2	
Forest loss ha/year	1'641'708		706'149		331'258	
Logging concessions (ha)		37'500'000		11'800'000		4'600'000
Timber estates allocated (ha)		6'400'000		3'100'000		1'300'000
Timber estates realised (ha)		2'400'000		900'000		500'000

According to Cannon et al. (1994), of Indonesia's closed forests, 61% has been designated as production forest and allocated to logging concessionaires. By 1985, 51% of the production forest had been logged. Estimates of the annual deforestation rate diverge widely, partly because of the use of different definitions and partly because of weak data, ranging from 600,000 ha (Sève, 1999) to 2.4 million ha per year. Some

numbers are presented in table 2.In 1968, forests covered an estimated 77% of Kalimantan (41.5 million ha), which was about 34% of the total forest area of Indonesia at the time. By 1997 forest cover was estimated at 60% (31.5 million ha). In East Kalimantan, total land area is estimated between 19'720 and 21'140 km^2, depending on the source (RePPProt/WorldBank, 2001) versus MoF/Fatawi & Mori, 2000). But in both figures, forest land covers over 91% of the territory before 1980. This forest cover drop at 71% in 1997 according to MoFEC numbers (Table 2). East Kalimantan have the highest rate of conversion compared to the other Indonesian provinces, with the lost of 10 million ha within less than 30 years (WorldBank, 2001).

The fires, as mentioned in the previous sub-chapter 2.3.1., participated in 1992-93 and in 1997-98 to the forest degradation by huge amounts of hectares of forest burnt in Kalimantan (2.6 millions ha of forest). On top of that, by the year 2001, illegal logging was thought to be one of the most critical threats to forest capital, accounting for 50-70% of total log production. Casson & Obidzinski (2002) suggested that "illegal logging" is not a simple case of criminality, but a complex economic and political system involving multiple stakeholders. It should be viewed as a dynamic and changing system deeply engrained in the realities of rural life and regional autonomy created a supportive environment for it.

2.4.4 Environmental conservation and protection

Indonesia has a number of legislative texts that deal directly with environmental protection. Among these, the most important are: a) the Management of the living environment law of 1982; b) the law on the Conservation of the living environment and its ecosystem of 1990; c) the Spatial use management law of 1992 and d) the law on the management of the living environment of 1997. All these laws, which are phrased in a similar way and support one another, constitute a legal framework that:

- requires that natural environment be managed in a sustainable fashion
- establishes obligations to exercise a function of environmental protection to holders of rights on land and water
- sets out principles of land use
- defines environmental damages
- creates the legal basis for environmental audits
- determines penalties for environmental damages

Additionally, regulations require the preparations for environmental management and monitoring plans for the renewal of natural forest concessions, the awarding of new natural forest and the development of timber plantations (MOFEC decree). Despite this detailed legal and regulatory structure, environmental damage associated with forestry operations continue and may be increasing as the effects of newly opened logging blocks accumulate with those of previously harvested area (Sève, 1999).

2.4.5 Limnology and aquatic communities

According to Lehmusluoto et al. (1999) and Dudgeon (1992, 1995), **limnological** information of the Indonesian freshwater, lake, reservoirs, wetlands, swamps and river is limited. There have been only a few major limnological studies, such as the Sunda-Expedition in years 1928-1929, covering Sumatra, Java and Bali, and a great number of sporadic studies, restricted in area and depth, from the 1970s, 1980s and 1990s, and the most recent Expedition Indodanau which covered the major lakes and reservoirs in Sumatra, Java, Bali, Lombok, Flores, Sulawesi and Irian Jaya (Lehmusluoto et al., 1999). A status of limnology in Indonesia has been presented by Nontji (1994) as well as a review of current knowledge of Indonesia's major freshwater lakes by Giesen (1994).

There are more than 400 freshwater **fishes** known in Indonesia, mostly Cyprinidae, Cyprinodontidae, Balitoridae, Bagridae, Siluridae, Gobiidae, Belotiidae, Aplocheneilidae, Channidae, Clariidae, Poccilliidae, Cichlidae, Helostomatidae, and Anabantiadae. In Kalimantan and Sumatra, there are more species than in Java, but the density is greater in Java. Java's native fish are both less abundant and less diverse than they were because of loss of forest, water pollution, sediment dredging and damming (Lehmusluoto et al., 1999). In their article, Lundberg et al. (2000) proposed an overview of recent ichthyological discovery in continental waters. This paper includes studies made in tropical Asia (the Oriental Realm, extending from the Indus Basin eastward to South China and to the Mollucas in Indonesia) and records works from Kottelat (e.g. Kottelat & Whitten, 1996a and b) and others.

Aquatic insect diversity and ecology in tropical Asian streams has been summarised in a recent book (Dudgeon, 1999). Lehmusluoto et al. (1999) summarised the available information concerning macroinvertebrates and benthic algae in Indonesia, but mentioned that information on fungi, bacteria, zooplankton, benthos, periphyton, and littoral and surface vegetation is not adequate enough for a review. Bits and pieces of information may be found from the 8'000 pages of reports of the Sunda-Expedition in "Archiv für Hydrobiologie Supplement" volumes published in 1931-1958, mainly on taxonomy (about 1100 new species reported by Ruttner (1931, 1932, 1940, 1952) and Thienemann (1930, 1931, 1932, 1959), on periphyton (Nurbakti, 1991; Sulisyo, 1991), benthos (Sylviani, 1992), macroinvertebrates (Rumpoho, 1987, Kusjantono, 1991; Kadarusman, 1991), and molluscs (Samanya, 1989), on biology of various lakes (Eyanuer et al., 1981; Universitas Andalas, 1984; Universitas Cendrawasih, 1984), and on ecology by Whitten et al. (1987a,b, 1996) and Green et al. (1976, 1978, 1995). All these references can be found in the article written by (Lehmusluoto et al., 1999) and the one concerning periphyton, benthos and macroinvertebrates are written in Indonesian language and could not be found.

In this study, as the mayflies (Ephemeroptera) could be identified to generic level, some information based on Sartori et al. (in press) are provided. The following litterature references can be found in this article. The first species described were *Rhoenanthus speciosus* (Potamanthidae) and *Atopopus tarsalis* (Heptageniidae) at the end of the 19th century (Eaton, 1881). Ulmer's famous work on mayflies of the Sunda islands[1] focused mainly on Java and Sumatra, with sparse data on Borneo (Ulmer, 1939). Nevertheless, he described 9 new genera and 12 new species from this island. Since that time, a few contributions have brought some new data (Demoulin, 1953, 1954; Peters, 1972; Allen & Edmunds, 1976; Müller-Liebenau, 1984; Grant & Peters, 1993; Wang & McCafferty, 1995; Wang et al., 1995). The only supraspecific modern synthesis of mayflies found on the Sunda Islands has been the publication by Edmunds & Polhemus (1990), as well as the recent survey of Ephemeroptera from the Oriental region (Soldán, 2001). At the end of the 20th century, 35 genera and 44 species were recorded.

Considering the available information, our study will contribute to the scientific knowledge in tropical ecosystems, not only on the evaluation of landscape and ecological water quality indicators, but also on basic knowledge on the stream biota itself (habitat and macroinvertebrates fauna) and on the relationship about logging activities and the stream ecosystem.

1. group of islands extending from the Malay Peninsula to the Moluccas southeast of the Asiatic mainland toward New Guinea. They include the Greater Sundas (Sumatra, Java, Borneo, Sulawesi, and adjacent smaller islands) and the Lesser Sundas (Bali, Lombok, Sumbawa, Sumba, and Flores, Timor, Alor, and adjacent smaller islands).

CHAPTER 3

Study Area

This chapter presents the geographic location of the study area inside a state-owned timber concession, Inhutani II. Management in this timber concession is described. Available information on natural features includes climate, geology, land systems and associated soils, hydrology, vegetation and fauna are presented.

3.1 Geographic location

The research area was located in the Borneo island, on the Indonesian part covering 73% of the total island area, more precisely, in East Kalimantan. Borneo is the third largest island in the world (after Greenland and New Guinea) with approximately 740’000 km^2.

In East Kalimantan, the study area was more precisely located in Malinau province which was previously part of Bulungan province. Bulungan was divided in October 1999 into three smaller provinces : Bulungan (18’000 km^2), Malinau (42’600 km^2) and Nunukan (13’800 km^2).

The study area itself, covering 8500 ha, was located at latitude 116°30'E and longitude 3°00'N, inside a state owned concession, Inhutani II (see figure 7 for location). The study area was usually reached by air from Jakarta to Balikpapan, then from Balikpapan to Tarakan and finally from Tarakan to Malinau using a local air line (DAS) which takes half an hour. These flights operated twice a week when weather allowed it. The usual transportation for local population was by boat on the river Sesayap. About 4 to 5 hours were necessary to go upstream from Tarakan to Malinau town with a speed-boat. From there, a logging road led to the camp inside the concession within 3.5 to 4 hours drive (~90 km). The duration of the journey mostly depended on the water level, as the Rian river had to be forded to reach the camp. The closest village, Long Loreh was about 30 minute drive from the camp. The entire journey, from Jakarta to the study area, was usually made over two to three days.

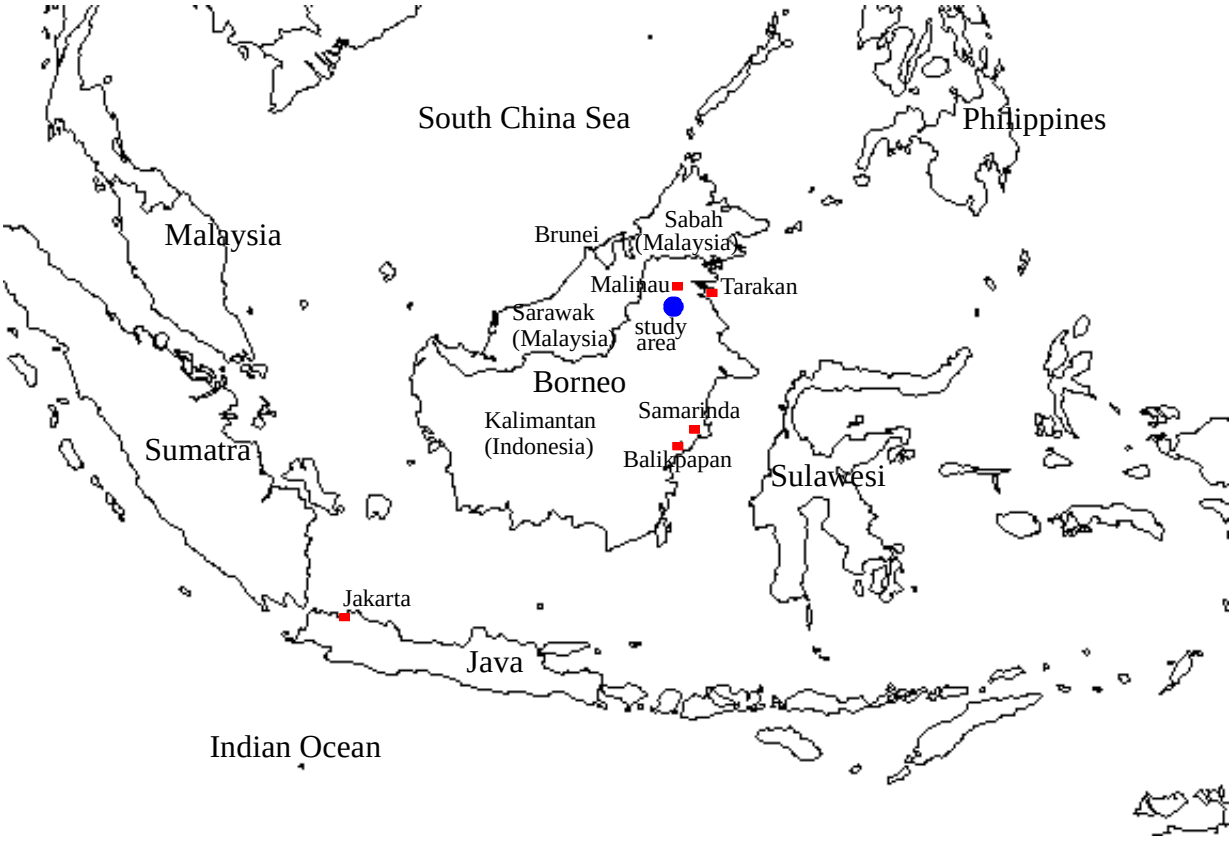


FIGURE 7. Partial map of South-East Asia with location on Borneo Island of study area in blue.

3.2 Inhutani II timber concession

PT Inhutani II Unit Malinau, a state-owned company, started its logging activities based on the Ministry of Forestry decree No. 64/Kpts-II/1991 issued on January 30, 1991. The area allocated to the concession covers 48’300 ha, located 116°-116°40’E latitude and 2°52’-3°14’ N longitude (see figure 8). PT Inhutani II concession is surrounded by PT Inhutani I and Bhakti Barito on the north side, Intracawood (ex-PT Inhutani I) on the east side, PT Meranti Sakti on the west side and by a protected forest, Bukit Condong on the south side. The 48’300 ha includes 14’180 ha of limited production forest, 23’890 ha of permanent production forest and 10’230 ha of unproductive land.

The concession started to log in 1991 in the north-east of the allocated area. Some of the firsts cutting blocks are very distant from each others. In order to minimise the spatial effect, we decided to remain in two watershed which contained most of the previously cut blocks. On these two watershed, the Seturan and the Rian, we were thus able to find a chronological sequence from logged in 1995 up to logged in 2000. A whole portion of the watershed, corresponding to cutting block logged in 1997 was inaccessible due to a broken bridge and was avoided.

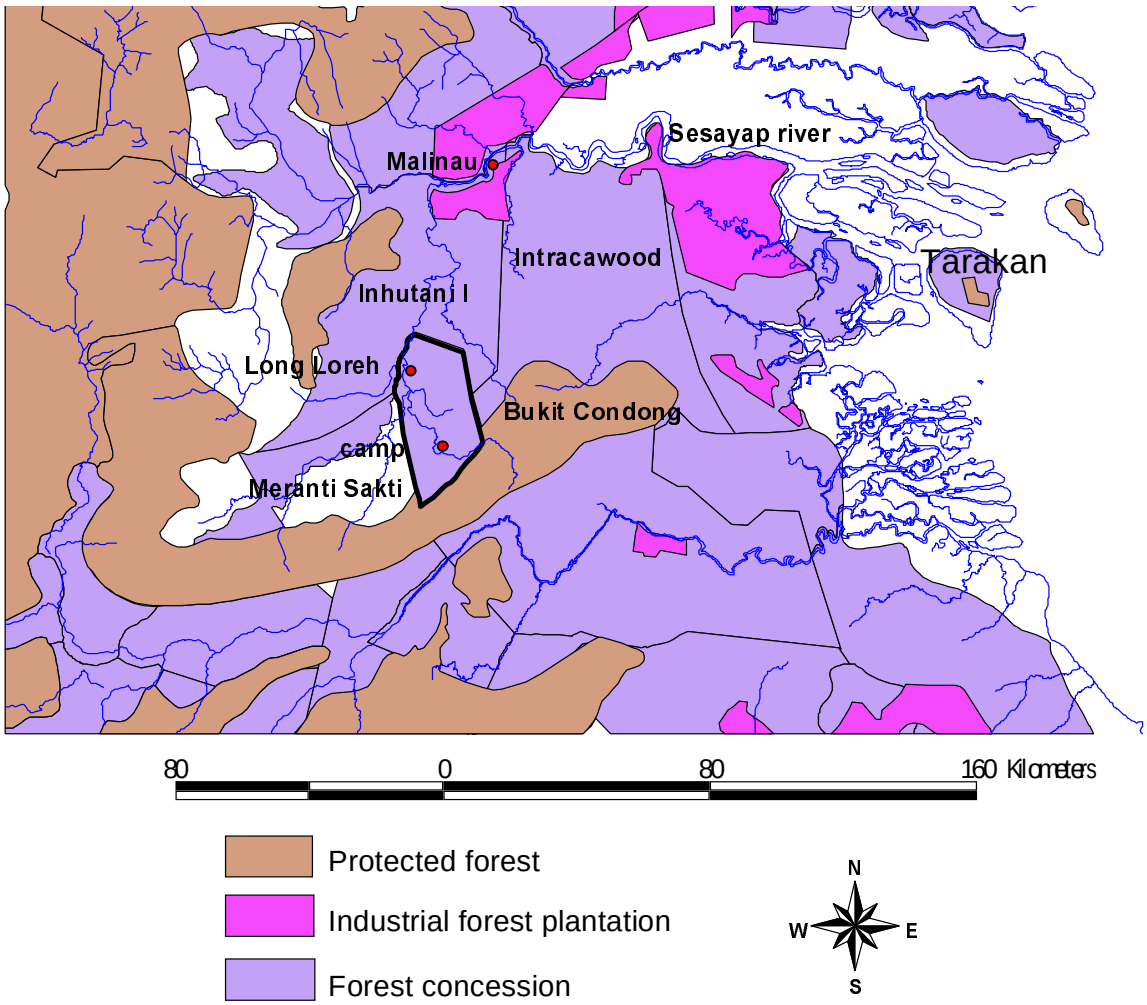


FIGURE 8. Localisation of Inhutani II concession (bold line) and other surrounding concessions. White areas are land which is not allocated for industrial forest plantation or forest concession, or land which are on renewal process at the time of the mapping. Source: Peta perkembangan pentaan batas areal kerjah HPH, 1992-1993, digitised and updated by GTZ, Samarinda. Original scale: 1:500'000.

Inhutani II operated under the Indonesian Selective Cutting and Planting Silvicultural System (TPTI: Tebang Pilih Tanam Indonesia), which replaced the previous selective cutting system (TPI: Tebang Pilih Indonesia) in 1989. The eleven steps which make up the TPTI system are summarised in table 3.

This TPTI system is designed to produce a sustainable supply of timber on a growing cycle of 70 years with a harvest every 35 years. Only trees over 50 cm diameter may be harvested in production forest and trees over 60 cm diameter in limited production forest. Logging is done in blocks, with each concession being divided into 35 annual blocks. The Annual Allowable Cut for each block is set by the Ministry of Forestry. At least 25 commercially valuable trees with diameters between 25 and 50 cm must remain after logging and post-logging enrichment planting is required. In principle, these requirements imply that approximately one cubic metre of timber would be harvested per hectare annually. Planning requirements are stringent and complex, with concessionaires being required to submit annual management plans, various work plans, environmental impact assessments and community development plans (Elliott, 2000).

Concessionaires pay a variety of royalties, fees and taxes including a volume-based reforestation fee which goes into a reforestation fund managed by the Ministry of Forestry. This fund is supposed to be used to fund reforestation activities but there have been a number of cases of Presidential misuse (Elliott, 2000).

TABLE 3. TPTI activity schedule: number of years before felling (T -3, -2 -1) and after felling (T +1 up to +19)

Nb	TPTI activity	Time relative to felling (T)
1	Working area organisation (boundary)	T -3
2	Inventory before felling	T -2
3	Infrastructure establishment (roads)	T -1
4	Felling (logging activities)	T
5	Liberation (removing of bushes, low growing vegetation,.)	T +1
6	Inventory of residual stand	T +1
7	Seedling procurement	T +2
8	Planting / enrichment	T +2
9	Tending/ first phase	T +3
10	Subsequent tending (a) liberation	T +4
	(b) thinning	T +9, 14, 19
11	Protection and research	continuously

The basic assumption of this TPTI system is that through its application, a perpetual supply of raw material to the forest industry can be assured without compromising the protective functions of the forest or the basic resources of soil and water (NRMP, 1993). The system assumes that the following conditions can be satisfied:

- minimum stocking of nucleus trees[2] before logging is 25 trees/ha. Nucleus tree must be 20 to 49 cm diameter at breast height and of commercial species
- the felling cycle is set at 35 years with an assumed diameter increment of 1cm per year
- tolerable loss of nucleus trees during initial exploitation is not stated but 10% could be considered as reasonable
- mortality of nucleus trees during the cycle is not acknowledged. FAO studies suggest a loss of 1% per year.

A long term management plan (RKPH: Rencana Kerja Pengusahaan Hutan) on 20 years is prepared by the concessionary. This plan should report past and future management activities including the eleven steps from TPTI guidelines, as well as forest product, marketing, protection, development of local communities, proposals for research and conservation, 20 year cash flow, profit and loss statements and production projections (amongst others). The RKPH divides the concession area into seven equal blocks, each covering a five year working period (RKL: Rencana Kerja Lima Tanhun), such as in figure 9. This covers the 35 years cycle, but the concession area is granted for 20 years. Every RKL is divided into 5 equal blocks for annual working plan (RKT: Rencana Kerja Tahunan), each divided in 100 ha plot (petak in Indonesian language).

Hundred percent inventory of all commercial species with diameter >20 cm is carried out during step 2 (table 3). Beyond this distinction, the enumeration provides no qualitative assessment of recoverable tim-

2. commercial trees species to be left for the next cutting cycles. They have to be clearly marked in the field.

ber volumes. The results are summarized in an inventory report (Laporan Hasil Cruising, LHC). Commercial target species are drawn from this inventory and form the basis for all further calculations and harvesting control. The RKPH includes a calculation of the Annual Allowable Cut (AAC):

$$AAC = \frac{A \times V}{35}$$

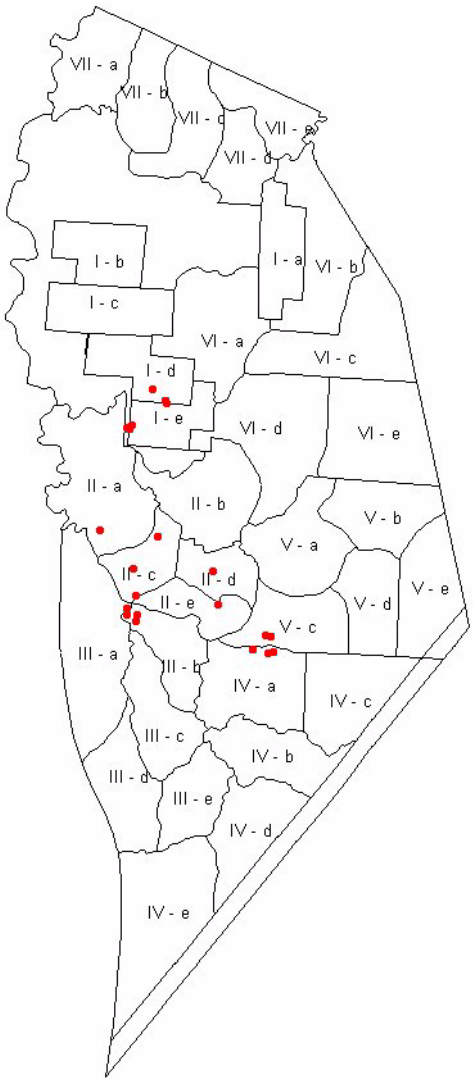
where A = area of available forest, V= average volume of commercial species per hectare (50 cm diameter and up) from the inventory and 35 = cutting cycle.

TABLE 4. Area and volume target for each year and actual area and volume logged. Depending on which Inhutani II report are consulter, numbers are different, such as in column «annual production» versus «other annual production».

Years	Target area (ha)	area logged (ha)	annual production target (m^3)	annual production (m^3)	Timber quantity (m^3/ha)	other annual production (m^3)	Sold price (rp/m^3)
1991-1992	1’000	900	30’400	26’421	29.35	28’747	88’532
1992-1993	900	850	29’000	26’430	31.09	27’318	85’845
1993-1994	900	600	39’160	20’720	34.5	20’656	154’202
1994-1995	900	600	24’000	22’875	38.12	42’290	122’982
1995-1996	1’100	1’000	41’200	33’240	33.24	30’018	115’389
1996-1997	1’100	900	37’535	17’631	19.5	19’975	191’371
1997-1998	775	450	26’444	22’757	50.5	30’374	176’893
1998-1999	904	635	30’952	20’604	32.4	16’121	311’234
1999-2000	925		26’183			25’018	387’104
2000-2001						25’575	572’337

Since the AAC equation does not reflect loss due to waste, breakage, decay or other losses, two correction factors have been introduced which are used to obtain the Annual production quota (JPT) as follows: JPT = AAC x 0.56. This consists of a "utilisation factor" (0.7) and a "safety factor" (0.8). The resulting volume is species-specific. All subsequent production occurs within this species-specific target figure and within the designated annual harvesting area. This volume per area limit becomes the cut-control mechanism within which Inhutani is relatively free to operate. Since there are no controls on the level of utilisation during the logging activities, the company has no incentive to make use of the volume cut and will tend to highgrade the stand level until it achieves its annual production quota (JPT) or until it reaches its annual harvest area target (NRMP, 1993).The annual cutting area set for Inhutani II concession consists of nine petak. Figure 9 presents the RKL 5-years cutting blocks. Production data was obtained for the past nine years which compares the approved annual production target and the actual annual production (see table 4).

Inhutani monitors its production closely and submits periodic production reports to the Ministry of Forestry. It is not uncommon for Inhutani to re-enter a specific petak during the course of the production year if it needs additional volume to meet the annual production target. Under-performance against this target, can carry a penalty generally consisting of a reduction in the next years target, although there is no evidence that this has ever occurred in the Inhutani II operation.



Legend:

RKL I, from a to e: years 1991 - 1996

RKL II, from a to e: years 1996 - 2001

RKL III, from a to e: years 2001 - 2006

RKL IV, from a to e: years 2006 - 2011

RKL V, from a to e: years 2011 - 2016

RKL VI, from a to e: years 2016 - 2021

FIGURE 9. Five-years cutting block (RKL) in Inhutani II concession. Red dots indicate the sampling site location. Source: Peta RKL Pengusahaan hutan III (2001-2006), Pt Inhutani II. Original scale: 1:50'000.

Certain aspects of Inhutani's operation were different from usual concessions. Inhutani II was not linked with a specific manufacturing complex. The management produced logs on instruction from the Samarinda head office towards specific log orders. These logs were either sold to specified industries or to log brokers who, in turn, arranged the sale to a final buyer. Buyers demanded only the best quality and generally insisted on "fresh cut logs". This significantly reduced Inhutani's flexibility. They work on specific species and volume orders. For example, they received in 1999 an *Agathis* order for 2000 cu.m (Klassen, 1999).

The list of commercial species which Inhutani fells is very limited and consists mainly of dipterocarps species: *Shorea sp.* (meranti merah), *Shorea parvifolia* (meranti puhti), *Shorea hopeifolia* (meranti kuening),

Dipterocarpus sp. (keruing), *Agathis* sp, kapur, semangkok, and nyatoh. Of these, *Shorea* sp constitutes 43.4%, Kapur 10.4%, *Dipterocarpus* sp 7.9%, Agathis 2.35% and the other 35.9% of primary forest (AMDAL, 1997).

It is common practice within timber concessions to manipulate the reporting of species as determined by the surveying team, in order to match the annual target production. Inhutani II is no exception in this regard although, so far, this practice has been limited to a few trees of the less common commercial species which have been recorded as Meranti merah or Keruing. Since Inhutani supplies logs towards specific orders, the highest quality standards are applied. Holes and other main bole abnormalities are not tolerated, hence, a large percentage of the commercial trees are left standing at the discretion of the fellers since they do not get paid for rejected logs.

Conventional logging according to TPTI regulation: In organizing its harvesting activities, Inhutani II operates in much the same way as most other forest concessionaries in Indonesia. A petak or portion of a petak, is assigned to a production team consisting of a crawler tractor and a feller. The feller cuts the commercial trees according to the utilization standards specified by the company management. The tractor operator then progressively opens a skid trail network as he looks for the trees which have been felled.

There is little or no pre-planning in the extraction activity apart from the initial marking of potentially commercial trees during the 100% inventory. There is even less supervision of the extraction activity. Both the feller and the tractor operator are paid according to the final scaled volume which has met the company's quality standards. It is up to the feller to choose which of the marked trees he will fell and it is up to the tractor operator to decide whether he will spend the time and effort to find and extract the felled tree.

In conventional logging, stock maps are not consulted during the logging activity. The feller searches for commercial trees and the tractor operator searches for the felled trees. Slope is seldom a constraint since virtually all areas can be reached from more than one direction and since side-cutting is relatively easy, even on steep slopes. Stream are routinely crossed by the tractor operator and pose virtually no constraint on the conventional approach to logging. In one petak, the gentle slopes of the Seturan flood plain were the most lightly logged. According to the production crew, the area was too wet, however inspection of the area suggest that the relative scarcity of the primary target species and the heavy buttressing of many of the trees may have been an equal or more significant factor in largely avoiding the easier ground (Klassen, 1999).

A collaboration with CIFOR started in 1997 to implement **Reduced Impact Logging (RIL)** activities. References on RIL studies can be consulted under «State of the Art» chapter. Inhutani II implemented RIL in 1999 on a 100 ha block, in 2000 on 200 ha (2 blocks) and for year 2001 they will add up to 300 ha (3 blocks). Some of the results have been published by Sist et al. (2002).

3.3 Natural features of the study area

3.3.1 Climate

Borneo lies on the equator and has a moist, tropical climate. Temperatures are relatively constant throughout the year averaging 28°C and ranging from 25°C and 35°C in lowland areas. At this latitude, the main climatic variable is rainfall. The pattern of rainfall in Indonesia is determined by two monsoons, the southeast or "dry" monsoons (May-October) and the northeast or "wet" monsoons (November –April). The northwest monsoons are generally wetter than the southeast monsoons (MacKinnon et al., 1996). The ten-

dency of rainfall maxima to occur in the transition months is modified considerably by the positions of localities relative to the mountains ranges and coastlines of Borneo and the monsoon winds. Interior stations, such as Pensiangan and Danum Valley (South Sabah), tend to exhibit rainfall maxima following the equinoxes, with least rain in July-September, when the southwesterly monsoons, which has travelled across the Bornean landmass, is at its height (Walsh, 1996). The study area is approximately 150km interior from the East coast. According to Inhutani II reports, months with higher rainfall are June and November and months with lower rainfall are January, May and December.

The per humidity index (Walsh, 1992) measures the degree of continuity of wetness of the mean rainfall regime by ascribing positive and negative scores to monthly rainfall means depending on the extent to which they fall below or exceed 100 mm. Tropical rainforest areas have a per humidity index within the range +5 to +24. Most of northern Borneo falls in the “superwet” class (per humidity Index +20 or greater) and is considerably less seasonal than many other rainforest localities, especially in the neotropics and Africa. According to its location, the concession belongs to this “superwet” class. This is also confirmed by Oldeman et al. (1980 as cited by MacKinnon et al., 1996) who mentioned that this region of East Kalimantan had very few months with rainfall of less than 200 mm. Most of the hilly inland areas receive between 2'000 and 4'000 mm of rain each year.

Figure 10 shows that data collected at four locations: a) from Malinau station, located 90 km north from the study site, for two time intervals 1922-1980 and 1975-1995. Both time intervals gave the same average; b) data from the camp were recorded from February 2000 to April 2001. They were taken very irregularly, such that the graph has to be considered as an estimation only. March and November 2000, as well as February 2001 were fully recorded, whereas February, April, May and December 2000 had between 13 and 17 days recorded and the remaining months had between 20 to 28 days records; c) data from Danum Valley, located in Sabah, as comparison and d) data from Binhut station, located inside the concession, 20 km north from the sampling sites.

Particularly heavy drought, associated with El Niño phenomenon occurred in 1997-1998 causing extensive fire in East Kalimantan. Although events of weak intensity occur every 3-4 years, the strong events seldom occur less than 6 to 7 years apart and only eight very strong events (such as 1982-83) have occurred in nearly five centuries (Enfield, 1992 as cited by Walsh, 1996). This may explain the low rainfall quantity expressed from January 1998 to July 1998 in Binhut (figure 10, graph d), and as well in Danum Valley (figure 10, graph c). According to (AMDAL, 1997) report, 2 months with less than 100 mm rainfall occurred only once in 1983 on the whole data set collected from at Malinau 1975 to 1991, one of El Niño year too (1982-1983).

Rainfall events in the study area seemed similar to the one described at Danum Valley by Douglas et al. (1999). During the two field seasons (July-August 2000 and April-May 2001), rainfall events included many short rains of low-intensity rain, but also ones of high intensity, short-duration storms (which produce rain with large drop sizes and thus high erosivity), and occasional persistent heavy rains for many hours (personal observations).

Average temperature recorded at Malinau climate station from 1975 to 1995 (AMDAL, 1997) is 26.7 with maxima reaching 31° in average and minima 23° in average. Temperature are very constant. At the camp, open area surrounded by some trees, average temperature are of similar order, 26.3°C with maxima reaching 31.5 and minimal 21.3°C.

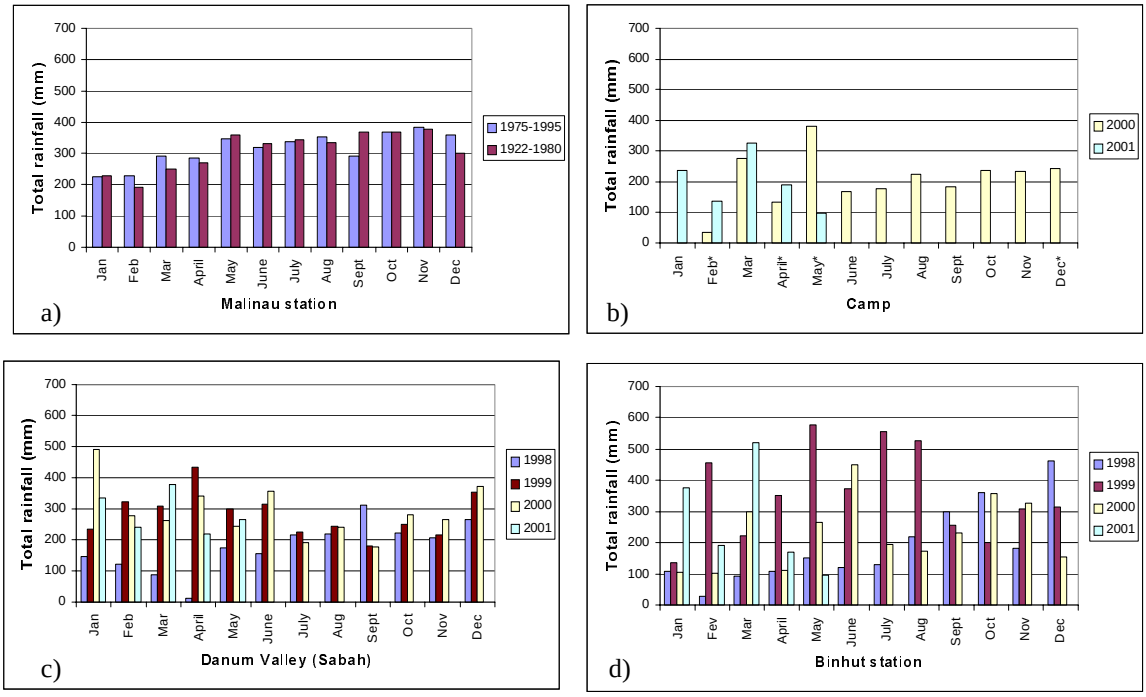


FIGURE 10. Rainfall data from a) Malinau station, b) Camp inside Inhutani II concession, c) Danum Valley (Sabah, Malaysia) available on internet (http:\\danum.swansea.ac.uk) and d) Binhut station inside Inhutani II concession. For b), c) and d) data stop in May 2001.* months with 15 to 17 days of rainfall records only. Data for a) and d) taken directly from unpublished reports.

Average humidity at Malinau station from 1975 to 1995 is 84%, ranging from 83.3 to 85.9% from January to December. Average humidity recorded at the camp from February 2000 to April 2001 is 85%. Average humidity reached 93% in the morning around 07:00, decrease until mid-day to reach 75% at 12:00 and increase toward evening, 86% recorded at 19:00.

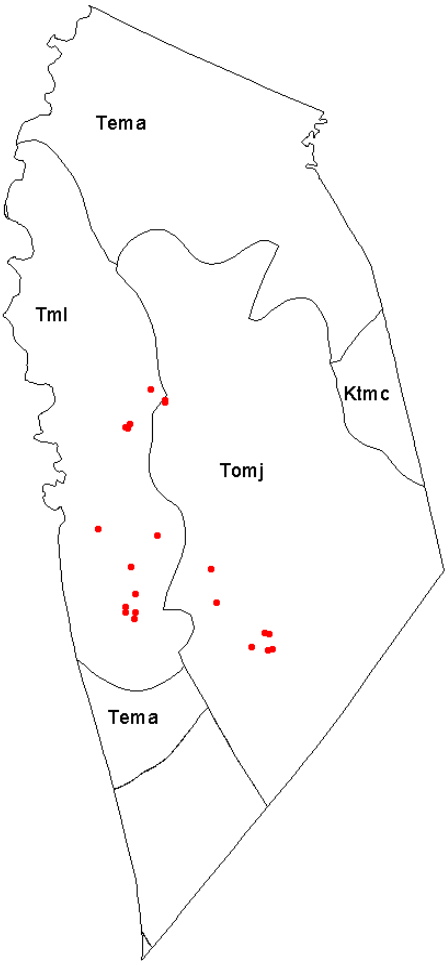
3.3.2 Geology

The Indonesian region is dominated by three major tectonic plates, the southeast Asian plate, the Indo-Australian plate and the Pacific plate, as well as several smaller platelets (Katili, 1989 as cited by MacKinnon et al., 1996). Western Indonesia, comprised of much of Kalimantan, Sumatra and west and central Java, is composed predominantly of continental crust, as is much of the shallow sea floor between these islands.

Until recently, it was believed that the western part (the Malay Peninsula, Sumatra, Java, Borneo and western Sulawesi) was derived from Laurasia (250-200 Ma, during the Triassic), while the eastern islands, including the rest of Sulawesi, were derived from Gondwanaland much later (Audley-Charles, 1981 as cited by MacKinnon et al. (1996). But in the light of more recent paleontological and geological discoveries, an alternative theory has been proposed. This suggests that this western part were not part of Laurasia but separated from Gondwanaland much later, in the mid-Jurassic (190-160 Ma) and Cretaceous (140-65 Ma) (Audley-Charles, 1987; Burrett et al., 1991, as cited by MacKinnon et al., 1996). After several drifts,

plate collisions, climatic events and changing sea level, Borneo found its approximately present position during the Oligocene, 30 Ma ago.

Publication of systematic geological maps is less advanced for Kalimantan than for any other part of Indonesia (figure 11). In 1979-1982, geological field work (Anonymous, 1982) was carried out on an area delineated by the borders of East Kalimantan with Sarawak and Sabah (Malaysia) to the west and the north, longitude 117° E to the East and latitude 2°N to the south, representing an area of approximately 48’000 km^2.



Tema: Malinau formation: feldsphatic sandstone, clayey and micaceous, grey-greenish grey; medium to coarse grained; poorly sorted, thickness of bed 20-50 cm, locally several meters; interbedded with siltstone or argillite, dark grey to black, micaceous and calcareous; Middle Eocene age; was deposited in a shallow marine environment.

Tml: Langap formation: white tuff, chalky; conglomerate, clast about 80-90% consist of clayey sandstone and mikly quartz, in a coarse grained sandstone matrix; shows cross-bedding, contains some thick coal seam; Late Miocene age, possible lacustrine deposits; thickness of unit about 50-100m.

Tomj: Jelai volcanic rock: volcanic breccia, tuff, lava breccia; basaltic-andesitic lava flows.

Klmc: Mentarang formation Embaluh group: sandstone bluish grey to greenish, fine to medium grained, formed by quartz, feldspar, mica and contains small rock fragments; intercalated with argillites and shale, locally breccia and conglomerate; flysh type; Late Cretaceous-Paleocene age; was probably deposited in a continental slope on edge of oceanic basin.

FIGURE 11. Red dots indicate location of sampling sites. Source: legend and layers come from the geological map of the Malinau, sheet 1819, East Kalimantan by the Geological research and development centre, Bandung, 1995.

The geology in the study area is both monotonous in nature and structurally complex. It mainly comprises thick flysch[3] type sedimentary formations, dated cretaceous (150 Ma) to lower Eocene (50 Ma), which cover 80% of the surface area. These are made up of a monotonous succession of sandstone, siltstone and

3. sequence of shales rhythmically interbedded with thin, hard, graywacke-like sandstones.

argillite beds, later tightly folded and faulted. This geological work revealed interesting mineralisation, including an extensive alluvial cinnabar occurrence in an east-central area where coal seams of several meters thick were found in the central Upper Miocene (25 Ma) basin of Langap.

Figure 11 presents the different geological formation encountered inside the Inhutani II timber concession. According to this map, the study area (red dots) belongs to the Langap formation (Tml) and to the Jetai volcanic rock (Tomj). However, by comparing the sketch map from the geological survey (Anonymous, 1982), with this map, the different geological formation do not cover the same areas from one map to the other. It is therefore difficult to confirm to which geological formation the study area belongs to.

3.3.3 Land systems units and associated soils

Knowledge concerning soil distribution in Kalimantan is generally limited: 90% of soil survey reports produced by the Centre for Soil Research have been for specific project sites for transmigration, tree crop estates or irrigation schemes. The majority of Kalimantan soils have developed on rolling plains and dissected hills on sedimentary and old igneous rocks. These soils range from strongly weathered and acid ultisols to young inceptisols. High levels of weathering, leaching and biological activity are characteristic of Bornean soils. The island's rocks are poor in metal bases, and Bornean soils are generally much less fertile than the rich volcanic soils of Java (MacKinnon et al., 1996).

The current land use classification is still based on a consensus for forest landuse plan (TGHK: Tata Guna Hutan Kesepakayan) established in 1984. The functional categories of forest land were originally delineated on small scale maps (usually 1:500'000), out of date and later transformed to larger scale maps. This TGHK maps contain neither any information about vegetation cover, nor characteristics of the physical environment, which have an important influence on land capability. Despite this and other serious deficiencies, the TGHK maps have formed the basis for regional forest land allocation decisions (Sève, 1999).

There are eight groups of land system unit on the Inhutani II Malinau concession (AMDAL, 1997). According to figure 12, most of the sampling sites are located in TWH (Teweh) land system unit with only few into PDH (Pendreh) land system unit. The associated soils for both land system units are Podsolik ortoksik where the solum is > 60 cm depth and both Alluvial gleik and Gleysol hidriks where the solum is between 20 to 60 cm depth.

Most of theses eight land system units are associated with three kinds of soil groups with different designations:

(1) Podsolik Ortoksik (MacKinnon et al., 1996) or Orthic Tropodults (Anonymous, 1975 b) or Orthic Acrisols (FAO/UNESCO, 1974), associated with MPT, MTL, TKR and PDH

(2) Alluvial gleik (MacKinnon et al., 1996)or Typic Tropaquepts (Anonymous, 1975 b) or Gleik Fluvisol (FAO/UNESCO, 1974), associated with TWB, TWH and BKN

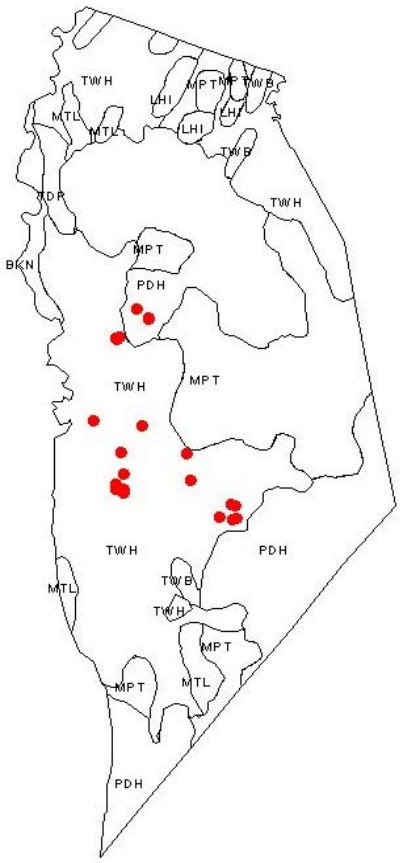
(3) Gleysol hidrik (MacKinnon et al., 1996) or Typic Tropaquent (Anonymous, 1975 b) or Hidric Gleisol (FAO/UNESCO, 1974), associated with TWB, TWH and BKN

(1) Podsolic ortoksik is spread over the entire study area, mostly on rolling hills and mountain areas. It belongs to the **ultisols** (acrisols) and covers the main part of northeastern Borneo. These strongly weathered soils form a high proportion of the red-yellow podsolic soils typical of the rolling plains of Kalimantan. Podsolic ortoksik is characterised as an old, infertile soil, with loam and clay. These soils are difficult to utilise intensively because of low nutrients levels beneath the topsoil and the combination of high aluminium levels and strong acidity. Traditionally local people have worked these soils by shifting cultivation, with a short cropping regime and a longer fallow to allow fertility to recover. This allows the topsoil

to regain some humus and organic matter, which are important as stores of nutrients and for regulating soil moisture and temperature (MacKinnon et al., 1996). In this area, podsolic ortoksik soil has a moderate to deep solum depth. Its drainage is moderate to fast. The colour varies from dark brown to yellow. It covers about 44’450 ha, equivalent to 92,1%, on most of the concession area.

(2) The alluvial gleik mostly occurs along rivers and plain alluvium. It belongs to the **inceptisols** type, the most common soils in Kalimantan, with moderate weathering and with a distinct profile (MacKinnon et al., 1996). In the concession area, this soil is formed by river sediment eroded from Tertiary siliceous sandstone and shales, is poorly drained and is some of the least fertile soil. Its solum is relatively deep and the colour is grey to dark brow. This soil covers about 1’225 ha, equivalent to 2,5% of the concession area.

(3) The gleysol hidrik also occurs along river and plain alluvium and its characteristic is about the same as the alluvial gleik. Soil colour is similar, grey to dark brown. This soil covers about 2’625 ha, equivalent to 5,4% of the concession area.



	soil depth (cm)	slope (%)	hillslope length (m)	area (ha)
MPT	60-90	25-40	100-200	8’100
MTL	100-150	25-40	---	1’350
TDR	26-50	15-25	> 500	660
LHI	26-50	25-40	200-500	640
PDH	26-50	> 40	200-500	15’415
TWB	100-150	25-40	50-100	690
TWH	> 90	15-25	< 50	20’240
BKN	> 150	0-8	---	1’225

FIGURE 12. Concession area with land system units with main characteristics such as soil depth, slope, hillslope length and area covered inside the concession. Red dots show sampling sites. Source: Land systems and land suitability, 1987. Malinau, sheet 1819 and Longbia, sheet 1818. Original scale: 1:250’000.

Most of the hilly area's land system are Maput (MPT), Mantalat (MTL), Tandur (TDR), Lohai (LHI), and Pendreh (PDH). The flat areas consist mostly of Tewai Baru (TWB), Teweh (TWH), and Bakunan (BKN) (figure 12).

Potential erosion is calculated in ton/ha/year. The equation takes into account many factors, such as erosivity due to rain intensity, soil erosivity, slopes, etc. (AMDAL, 1997). Half of the concession can be considered hilly with relief amplitude of 50-200m and the remaining part mountainous (more the 300m elevation). This may also be expressed by the slopes. According to Inhutani II data, around 25% of the area has less than 15% slope, 30% has between 15-25%, 38% between 25-40% and less than 10% has >40% slope. For the concession, the potential erosion reached several values according to the topography:

- 2'000 ton/ha/year for more or less flat area (slopes 15-25% with length relatively short (less than 50m), TWH unit);
- 7'000 ton/ha/year for sedimentary hills with 25-40% slopes with length between 100-200m (MPT unit);
- 9'900 ton/ha/year for sedimentary mountains with slopes >40% with length between 200 to 500m (PDH unit).

Record in 1996 (AMDAL, 1997) indicated that actual erosion in the concession was estimated as ranging from 0.4 ton/ha/year up to 3'214 ton/ha/year depending on the vegetation cover and the relief.

3.3.4 Hydrology

Borneo is dissected by large rivers which run from the interior heartland to the coast and provide the main routes of transportation and communication. The island host Indonesia's three longest rivers: the Kapuas (1'143km), the Barito (900 km) and the Mahakan (775 km). Human settlements in Borneo are concentrated around the coast and the main rivers and lake systems.

TABLE 5. Physico-chemical parameters measured 4 years prior to the study in Inhutani II concession in several streams inside the concession (AMDAL, 1997).

	Gongsolok	Langap	Seturan	Lemata	Kopiak	Samuda
Turbidity (NTU)	6	5.3	7.5	5.5	4.6	5.5
Temperature (°C)	27	28	28	27	28	28
Suspended load (mg/l)	12	18	20	10	8	12
pH	5.5	6	6	6	6	6.0
Dissolved organic (mg/l)	3.1	3.8	4.2	4.8	3.9	4.2
CO2 (mg/l)	2.1	1.4	2.4	1.8	1.5	2.0
Alkalinity (mg/l)	18	18	14	10	26	14
Base Ca (mg/l)	32.1	14	16.1	26.1	22.1	10.1
Base Mg (mg/l)	16.2	10.2	13.2	13.4	10.0	12.1
N-NO2 (mg/l)	0.002	0.001	no data	no data	0.001	no data
N-NO3 (mg/l)	0.049	0.035	0.034	0.044	0.021	0.051
N-NH3 (mg/l)	0.2	0.209	0.155	0.127	0.104	0.164
ortho-PO4 (mg/l)	0.022	0.034	0.039	0.009	0.043	0.018

The concession area includes several rivers, such as Sidi, Gongsolok, Krukut, Nyarang, Langap, Gongsolok Hulu and Jakut, all belonging to the Malinau watershed (figure 13). But the two larger river systems

within the concession, are the Rian (10’185 ha) covering 24.2 km and Seturan (15’120 ha) covering 19.5 km, where all the samples were concentrated.

On six rivers, Gongsolok, Langap, Seturan, Lemata, Kopiak and Samuda, some physico-chemical parameters have been measured by Inhutani II concession (AMDAL, 1997). No information was available on the location of the samples along these rivers and how this data was measured. Table 5 presents this information, as it is the only data available on the area. The following comparison are made based on a report on water quality in France (SEQ-Eau, 2003). pH is low and indicates that these streams can be considered as acidic, temperature is high compared to temperate streams, but normal for tropical streams, turbidity values and suspended load are low (NTU of 15 is considered normal in temperature streams), and all other values, dissolved organic, CO_2, Ca, Mg, N-NH2, N-NO3 and ortho-PO4 are lower than the reference value for streams of good quality in temperate climate.

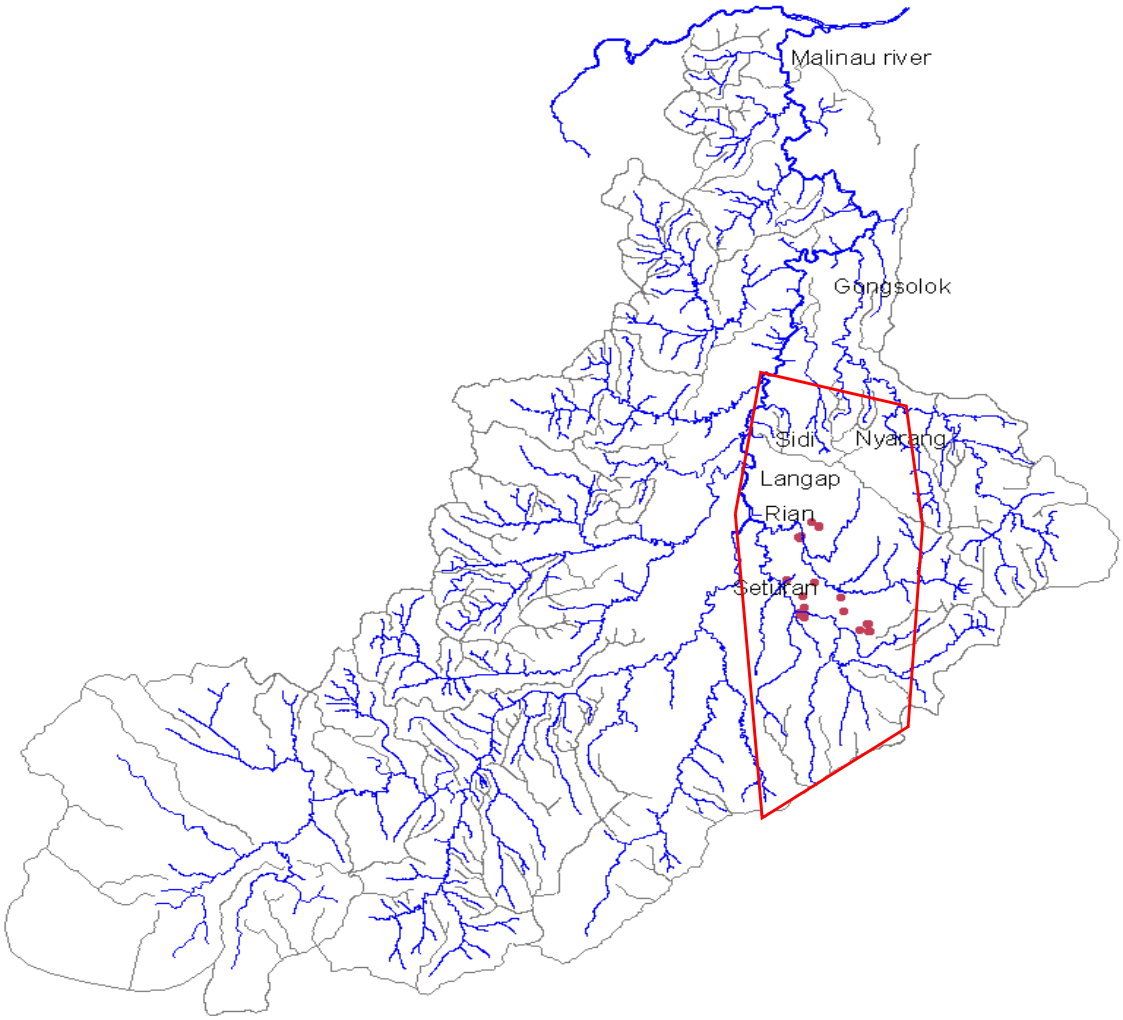


FIGURE 13. Malinau watershed and sub watersheds delineated in grey. Inhutani II timber concession delineated in red. Red dots show sampling sites

3.3.5 Vegetation

Borneo supports some of the largest expanses of tropical rainforests in Southeast Asia, providing some of the most species-rich habitats on earth. The island is a major centre for plant diversity, with 10'000 to 15'000 species of flowering plants, a flora as rich as that recorded for the whole African continent, which is 40 times larger. It includes both Asian and Australasian elements.

The rainforests of Borneo have had a long and relatively stable history. Earliest evidence of the occurrence of dipterocarps in Borneo is from fossil pollen in Sarawak from more than 30 million year ago (Muller 1970 as cited by MacKinnon et al., 1996). This long history has allowed a great diversity of plants to evolve.

Borneo has at least 3'000 species of trees including 267 species of dipterocarps, the most common tree family in South-East Asia. They also constitute an important group of commercial timber trees. Of these dipterocarps 58% are endemic to the islands. Endemism levels are high through the whole flora with about 34% of all plants, but only 59 genera (out of 1'500), unique to the island. Areas of plant richness can be associated with soil types (MacKinnon et al., 1996).

The lowland Dipterocarps forest

Lowland dipterocarps forest is the most extensive forest formation in the concession. Dipterocarps (so named after their winged fruits) grow as very tall trees with canopy heights commonly reaching 45 and sometimes 60 m or more. In the richest formations 10% of all trees and 80% of all emergent are dipterocarps (Ashton 1982 as cited by MacKinnon et al., 1996). Tropical rainforests of this stature and this density of top-of-canopy trees are unique to dipterocarps forest (Whitmore 1984a as cited by MacKinnon et al., 1996). The combination of very high stocking of trees with huge boles, commonly 20 m long or more, and of relatively light weight has encouraged extensive exploitation of dipterocarps forests throughout South-east Asia.

According to Inhutani II report (AMDAL, 1997), primary forest is estimated to cover about 68% of the total area, secondary forest covers 25%, non-forested land including old shrubs, grassland and settlement cover 5% of the area and the remaining 2% are the unknown area covered by clouds at the time of evaluation. The forest in the concession area is composed essentially by dry lowland forest (90%) and swamp forest (10%). Canopy is mostly dominated by Dipterocarps trees (81%). Most of the vegetation is constituted by high potential forest (80%), 8.5% by forest of medium potential and 0.1% by forest of low potential.

In the high potential forest, 46 species of commercial value were identified totalling in average 195 trees/ha. In the order of decreasing number of tree/ha: *Shorea* sp (meranti merah) has 30 trees/ha; *Dipterocarpus* sp. (keruing putih) has 20 trees/ha; *Dipterocarpus* sp. (keruing), *Shorea hopeifolia* (meranti kuning) and *Shorea parvifolia* (meranti putih) have 15 trees/ha. The following trees have less than 10 trees/ha: *Wellughbeia* sp. (keomatao), *Fibraurea tinctoria* (ponggaya), *Hopea dryobalanoides* (cah), *Durio lowianus* (durian), *Dipterocarpus* sp. (keruing merah), *Dehaasia* sp (lemea), *Shorea* sp (luhui), *Elaeocarpus* (lutua), *Dipterocarpus caudiferus* (mentaya), *Knea cinerea* (ngah), *Artocarpus anisophyllus* (tarap). In the medium potential forest, 26 species of commercial value totalling 210 trees/ha in average, were identified. The majority of them are *Shorea* sp (meranti merah) with 65 trees/ha in average

Numerous small and pole-sized trees dominate the lower story to a height of 20 m, with most of the species being non-dipterocarps. The understory is moderate to dense, dominated by trees below 10 cm diameter belonging to common families such as Annonaceae, Dipterocarpaceae, Euphorbiaceae and Rubiaceae. Most dense primary forests occurred on hill or mountain area.

Secondary forests are mostly located close to rivers. Most of secondary forests cover area used for shifting cultivation. Dominating vegetation is *Dekasia easia* (medang), *Gleichenia lincaris* (resam), *Hopea mengarawan* (merawan), *Melaleuca leucadendron* (gelam), *Calamus* sp (rattan), and coffee (*Coffea* sp). In slash and burn agriculture type, main crops planted are *Oriza sativa* (rice), *Manihot utilissima* (cassava), *zea mays* (corn) and nuts especially peanut (*Arachis hypogaea*). After two years, the land is left fallow by farmers, with some coffee plants. The fallow than grow into shrubs, before becoming a secondary forest.

Protected tree species: Based on the Ministry of Forestry decree No. 261/Kpts-IV/1990, there is one absolutely protected tree species called tengkawang (*Shorea* sp.), one species that produce tannin and gum (*Durio zibethinus*), and three species that produce bark or trunk (*Eusideroxylon zwageri* = ulin, *Diospyros* sp. = kanyetein, and *Diospyros sumatrana* = wax).

3.3.6 Fauna

Borneo shares much of its fauna with the asian mainland and the other Sunda islands, but shares few species with Sulawesi and the eastern islands. This division of the biota is known as the “Wallace line”. In relation to its size, Borneo is less rich in mammals than the smaller island of Sumatra (Table 6). This impoverishment can be explained by the fact that Borneo lies further offshore from mainland Asia and probably was separated earlier from the mainland by rising sea level (MacKinnon et al., 1996).

Most data mentioned hereafter are summarised from an unpublished report (Fimbel & O'Brien, 1999) following a faunal survey in the Inhutani II concession where this study took place. A total of 31 species of **mammal** were identified in the study area, belonging to 10 families (squirrels accounted for the highest number of species - nine). These observations represent approximately 60% of the mammal species that are likely to occur in the study area. Only two threatened species (i.e. species listed in the 1996 IUCN Red List) were recorded in the survey area: *Macaca nemestrina* and *Lutrogale perspicillata*. Both are listed as vulnerable.

TABLE 6. Species richness in the study area (Fimbel & O’Brien, 1999), on Borneo island and on other Indonesian islands (MacKinnon et al., 1996). Numbers in brackets are island endemic. *only Swallowtail butterflies species

	Study area	Borneo	Sumatra	Java	Sulawesi	New Guinea
Plants		10’000-15’000	9’000	4’500	5’000	15’000-20’000
Mammals	31	222 (44)	196 (9)	183 (19)	127 (79)	220 (124)
Resident birds	239	420 (37)	465 (18)	340 (31)	240 (88)	578 (324)
Snakes	34	166	150 (8)	7 (4)	64 (15)	98
Lizards	13			42 (1)	40 (13)	184 (59)
Amphibian	46	100	70	36 (10)	29 (19)	197 (115)
Fish	43 (10)	394 (149)	272 (30)	132 (12)	68 (52)	282 (55)
Butterflies	63	*40 (4)	49 (4)	35 (2)	38 (1)	26 (2)

The **bird** fauna of Borneo is typically Asian in origin and similar to that of Peninsular Malaysia and Sumatra, with rich representation of the hornbills (8 species), woodpeckers (18 species), pittas (13 species) and other forest families (MacKinnon et al., 1996). A total of 239 bird species were observed in the study area (Fimbel & O'Brien, 1999). Of these, 178 represent lowland-dependent forest birds, or approximately 73% of the 244 lowland forest birds in Borneo. Families with the most species recorded included Timaliidae (18 species), Pycnonotidae (12 species), and Picidae (12 species). Twenty-nine bird species are considered at risk from habitat disturbance: one endangered (*Ciconia stormi*); six vulnerable (*Argusianus argus*, *Carpococcyx radiceus*, *Lophura ignita*, *Rhyticeros corrugatus*, *Rollulus rouloul*, *Spizaetus nanus*) and 21

near-threatened. Nine species are Borneo endemics. Eight of the eleven Bornean kingfishers were recorded in the study area. Seven of the eight Bornean hornbills were recorded, with the Asian Black Hornbill (*Anthracoceros malayanus*), Rhinoceros Hornbill (*Buceros rhinoceros*), and Helmeted Hornbill (*B. vigil*) the most commonly observed species.

Borneo is probably one of the richest islands of the Sunda Shelf for fishes, amphibians, snakes and invertebrates, but figures are not so accurate for these less well-known groups (MacKinnon et al., 1996). Lang & Hubblel, (unpublished) captured and identified 38 amphibians species, 13 lizards, 34 snakes and 8 turtles from the study site.

A preliminary **fish** survey was conducted by LIPI in 1999-2000 (Rachmatika, 2000) and found that there were 43 fish species found in the study area. They belonged to 4 order, 10 families and 29 genera. The most common families encountered were Carps/Karper-karperan (Cyprinidae), Hillstream Loach/Selusur (Balitoridae) and Loaches/Jeler (Cobitidae). It was also found that at least 10 fish species were endemics to Borneo. Lepe fish, *Nematabramis everetti* was the most widely distributed fish in this area.

A total of 63 **butterfly** species (excluding Lyceneidae and Hesperiidae families) were recorded in the study area, but restricted to two study sites only (Fimbel & O'Brien, 1999). This is equivalent to species numbers recorded for a similar length of time at other tropical forest sites in SE Asia. It should be noted that the information obtained on butterflies is from a very restricted sampling period.

13 **insect orders**, consisting of 79 families, were collected from pitfall traps and 16 insect orders, consisting of 168 families, collected from sweeping (Fimbel & O'Brien, 1999). Three orders dominated: Diptera (flies and mosquitoes), Hymenoptera (wasps, ants, and bees), and Coleoptera (beetles). From both survey methods, and supplemental litter samples (ant transects and Winkler bags), ants (Hymenoptera: Formicidae) were the most abundant species collected (6185 ants of 134 species).

An unpublished preliminary study on **benthic macroinvertebrates** was conducted in the concession in 1998 in several streams. It was a qualitative assessment with macroinvertebrates identified with North-American identification keys. Unfortunately, the samples could not be found for comparison.

3.4 Socio-economic features

3.4.1 Population

The indigenous population in the Bulungan area belonged to several ethnolinguistic categories, such as Merap, Punan, Kenyah, Putuk and Abai. The largest ethnic group was Punan which was approximately 30% of the villages or about 17% of the whole population in Malinau town. Other groups such as Malay (Islamized Dayak) lived close to Malinau town.

Based on AMDAL (1997) report, population of Malinau in 1990 was 17'915 people, and in 1994 was 20,779 which consisted of 51.20% males and 48.80% females. Based on provincial statistics, the population was over 35'000 people in 1998. Most of the population were concentrated in and around the town of Malinau. This town counted 3'582 people in 1990 and 4'608 in 1994 (14.3 person/km^2). The two villages next to the camp, Langap and Long Lore hosted 320 and 516 individuals respectively in 1990 and 402 and 514 in 1994. Based on data from 1990, 47.8% of the population was less than 14 years old and were considered as non-active; 46.5% were active between 15-54 years old and 5.5% were older than 55 years old and considered as non-active.

The income of the population could be grouped into 8 professions: farmer (46.9%), timber company employee (30.8%), trader (7.4%), government official (6.2%), teacher (3.7%), worker (2.5%), taxi driver (1.2%) and others (1.2%). Side income sources were mainly farming (56.7%), picking forest products (33.3%) and trading (10%). Income per capita on average in 1994 was Rp. 286,300/person/year which was equal to approximately US$ 150/person/year.

The concession area had been used for timber and other forest products by local people living within and outside the concession area. The government encouraged migration of villagers from remote areas to cities for better access to infrastructure, such as schools and medical services. This has led many villages to move out from the area while still maintaining traditional links with it, especially for high value forest products. Diverse new activities have been developing over the past 3 years in this area including oil palm plantations, forest plantations, coal mining and logging. These are rapidly opening up the area. These new activities also bring changes in population (the majority of Inhutani II concession and coal mining workers are from outside the area and from the other provinces in Indonesia) and access to resources.

3.4.2 Land ownership

During the previous centralized regime the government consistently ignored the rights of local communities from 1970 up to 1999. Thus in the district of Malinau most land was designated as state forest and divided among concessions without any attention to the existence of local communities. With decentralization and the law on autonomy, the government is now prepared to recognize traditional rights (adat) and to respect traditional law. However, where many ethnic groups are living in the same location, each with their own rules on property right and resource use, it is not clear which “adat” to follow.

There are two kinds of land property in Malinau: **individual property** or private rights and community property (hak adat). Private rights include houses, yards, established gardens and fields around the village. These lands require usual procedure for registration of privately owned land. In average, individual land property is about 1 - 2 ha per household for short term agriculture and about 0.2 - 1.0 ha for long term agriculture usage. Administration of these lands is the responsibility of the village (until now only 1% of privately owned land in Malinau has been registered).

Community property. Traditional village boundaries have never been clearly delineated in East Kalimantan. Where valuable resources are located, the area might be claimed by several ethnic groups each comprising a “village”. “Adat” claims are thus too often overlapping and conflicting. The government therefore decided to standardize adat claims in the district. Each village has the right to designate an area of 5 - 10,000 ha as community land to be managed by the local institution. The latter, representing the village, is free to decide on the utilisation of this land, which at present is most likely to be forested land. This might include logging, mining or the collection of non-timber products and might involve a third party. The government will retain rights to control and supervise any activities on the “community land”.

Regrouping of villages and the resettlement of the Punan: because the villages were clan-based, many villages, especially those in isolated upstream areas and those of the Punan, consisted of only 5 to 10 families. The government is therefore trying to regroup villages. Up to the present this has been met with little success as people maintain their rights of having been established as an independent village. Similarly the government has tried to resettle the Punan who traditionally wandered over a large area within a kind of “home range”, without success. More Punan keep wandering away following their traditional way of life of hunting and gathering. The main problem consists in their reclaiming to be the original right holders.

Nowadays investors with permits to exploit natural resources issued by the district and local communities claiming traditional rights to the same resources (often beyond administrative boundaries) give rise to increasing conflict.

CHAPTER 4

Materials and Methods

The present chapter presents the sampling design. The original intended design could not be applied because of events which took place at the study sites between the first and the second year of field seasons. Indeed, it is difficult to describe a sampling strategy without mentioning the field unpredictabilities to be faced. Between June-August 2000 and March-May 2001, the process of decentralisation brought changes in the regional government. As a consequence, several small-scale permits (100 ha each) were issued inside the boundaries of the existing Inhutani II concession and outside concessionnaires (mostly small-scale Malaysian timber companies) started to log inside the area previously cut. As a result, the study area was affected and several sampling sites were destroyed or relogged within this 8- month interval. Sampling sites were considered as destroyed when a new logging camp was built a few meters upstream the site, or when material from the logging road newly built covered the stream, or when logging activities occurred at the same time as the sampling should be done.

"Sampling site" refers to the geographical location where habitat assessment occurred and where macroinvertebrates were collected. At each "sampling site", two "samples" were usually performed, the first in June-August 2000 and the second in March-May 2001. A "sample" designates a composite of the three Surber net collected. Coding for the samples was decided as follows: the first number designed the watershed (1 to 15), the second number designed the sampling site (1 to 4) and the third number, the sampling season (1= June-August 2000 and 3= March-May 2001). Environmental variables for each sample are provided in Appendix I.

Logging activities were examined at landscape scale and the results with a discussion are presented in chapter 5. At local scale, two aspects were examined. First, the relationships between the stream habitat (described by environmental variables) and its fauna (macroinvertebrates). This is the subject of chapter 6. Second, the impact of logging activities on both stream habitat and macroinvertebrate fauna were studied and is presented in chapter 7.

Materials and methods are described for both scales. Data obtained are statistically analysed using diversity indices, between samples comparisons and multivariate techniques.

4.1 Sampling design

Landscape scale in the study encompassed part of the Malinau river catchment, which included the Rian and Seturan rivers and their tributaries where all sampling sites were located (figure 14). Sampling sites were designed to be at the exutories of small headwater catchment, but as the delineation of these small catchments could not be ascertained due to inacurancy of the available maps, “sampling sites” will be used instead of “headwater catchment”.

All sampling sites were located in afforested habitat ranging from unlogged to logged forest. No agricultural practices were recorded in this area. No areas near villages or logging camp were sampled. Sampling sites located in unlogged forest acted as “reference sample”.

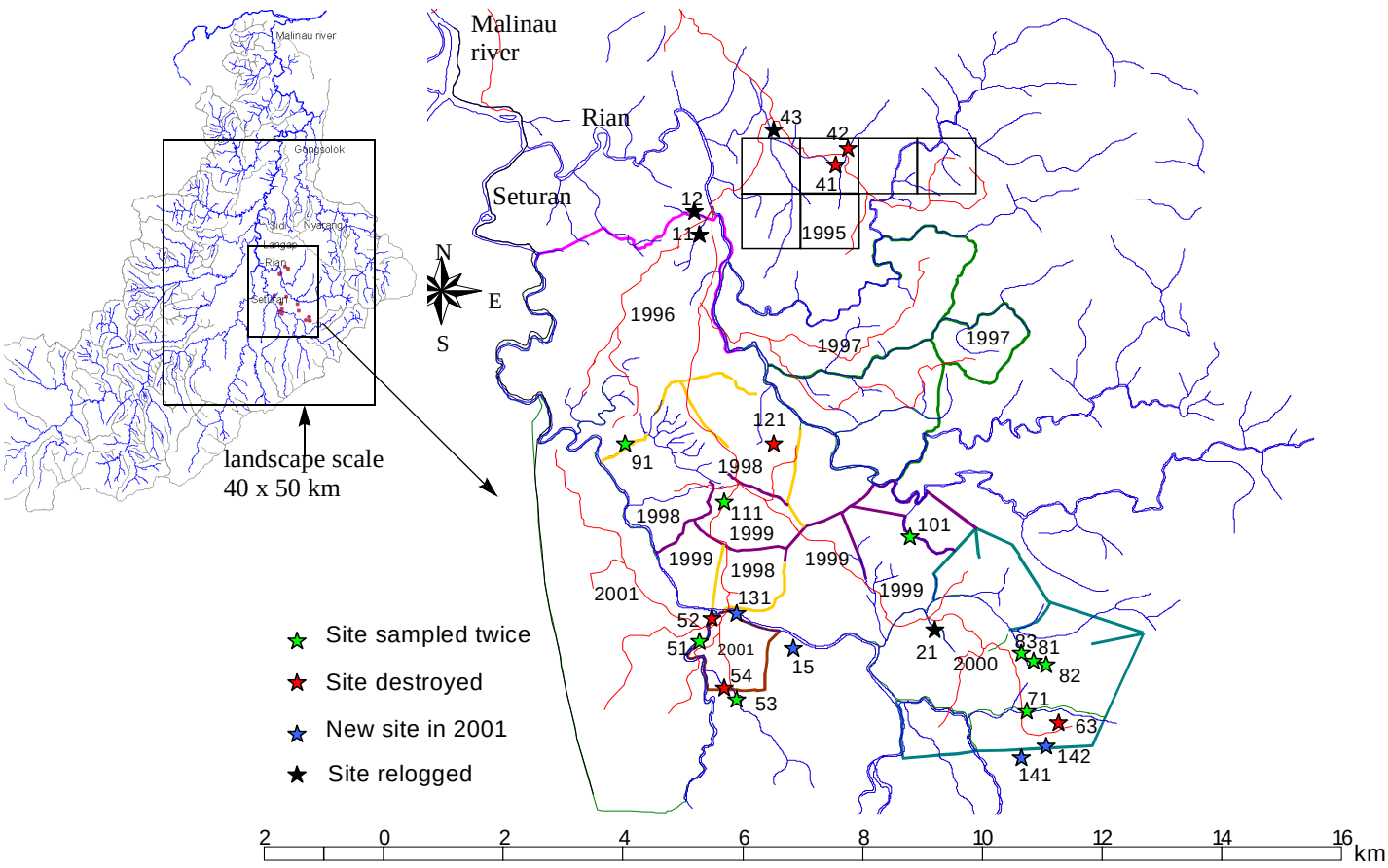


FIGURE 14. Part of Inhutani II concession with the Rian and Seturan watershed with cutting blocs from 1995 to 2001. Sampling sites are represented by stars. Logging roads are drawn in red and rivers in blue.

In this framework:

- length of logging roads were measured on the whole landscape (40 x 50 km as delineated in figure 14) in order to quantify the logging activities and to follow its intensification through the time, from 1991 to 2001
- area of different years of logging activities were chosen from the map 1:50'000 produced by Inhutani II concession (figure 14). 6 areas were selected: area logged in 1995, area logged in 1996, area logged in 1998, area logged in 1999, area logged in 2000 and area logged in 2001. Area logged in 1997 was inaccessible due to the bridge which was broken. This in order to study if the response of the ecological water quality to logging activities varies in function of the number of years after logging
- length of skidtrails and opening of the canopy where measured and mapped for 6 small headwater catchments, upstream from the sampling sites. This in order to try to estimate the intensity of logging as the proportion of the catchment area which was logged. These field maps drawn at scale 1:1'000 allowed to measure logging intensity only in 6 headwater catchments due to time constraints and changes brought about by relogging activities. Thus, logging intensity was not included in the analysis of environmental variables and macroinvertebrates results, because it was not available for all headwater catchments.
- response of the ecological water quality to logging activities was measured in two ways: at stream reach (sampling site), an habitat assessment was performed and at habitat units (runs and riffles), a biological assessment by collecting macroinvertebrates was performed. Environmental variables from the habitat assessment and macroinvertebrate taxa composition are first used to test ecological water quality and relationships between environmental variables and macroinvertebrates. They are then used to assess the impact of logging activities on the ecological water quality.

19 sampling sites were selected after several days of surveying in June 2000 (table 7). The main selection criterion was accessibility; all sites were within 30 minutes walking distance from a road. From the 1:50'000 contour map, it was not possible to chose the sampling sites according to the stream order or catchment size. That is why the selection was based on stream's width. An average of medium stream size (1,5 to 6 m) together with some larger streams was obtained. The medium stream size were estimated to belong to third or fourth stream order, this based on the 1:1'000 field maps produced during field work.

TABLE 7. Number of samples collected during the two sampling season, June-August 2000 and March-May 2001, according to the year when the logging activities occurred. * for new sampling site in 2001.

	2000 field season	2001 field season	Total
status of samples	No of samples	No of samples	No of samples
reference	4	*3	7
logged 1995	3	0	3
logged 1996	2	0	2
logged 1998	2	1	3
logged 1999	2	2	4
logged 2000	6	3 + 4 + *1	14
relogged		1 + 2	3
Total	**19**	**17**	**36**
destroyed		1 + 2 + 1+ 2	6

Field seasons were completed in 3 months of field work in June-August 2000 and 3 months in March-May 2001. Macroinvertebrate sampling did not occur, on purpose, at same time in year: June, July and August in 2000 and March, April, May in 2001 were chosen. This, in order to examine if season influenced the macroinvertebrate composition.

In March-May 2001, because of relogging activities occurring, several days were spent revisiting the concession to find out all the damages on the sites sampled in June-August 2000. Thus, intact sampling sites were sampled for a second time as planned and new sampling sites were found to replace some of the sites that were destroyed. As a result, most of the sites sampled in March-May 2001 were between 3 to 6 months after logging, meaning that the chronological sequence of 2000 field season was lost. 17 sampling sites were sampled, bringing the total number of samples at 36. Table 7 presents the number of samples collected in the two field season with each color allowing to follow the samples from 2000 to 2001. For example, in 2000, 4 samples were collected in reference streams. Among these 4 samples, 1 of them was destroyed and the 3 others were logged between 2000 and 2001 and were resampled as “logged 2000”. 3 new samples were collected as reference samples in 3 newly chosen streams.

Because of the low number of samples in each time interval, the samples are grouped in order to have enough samples for analysis (table 8): 4 to 5 years after logging activities; 1-3 years after logging activities and; 6 months after logging which represents all samples that were “on logging activities” in the broad sense: from the logging road building to several months after the tree harvesting. Stream sizes are mentioned here as it will have some importance that will be appear later on.

TABLE 8. Number of samples per stream size and per status. One sample being the composite of three Surber net.

Stream sizes	Chronological logging sequence					Total number
	reference	4-5 years	1-3 years	0-6 months	relogged	of samples
Stream < 6m	6	3	7	8	2	26
Stream 6 to 10m	1	2	0	5	1	9
River 30m	0	0	0	1	0	1
Total number of samples	7	5	7	14	3	**36**

Table 9 summarises the original sampling design as planed and the real one as applied in the field..

TABLE 9. Comparison of original sampling design as planned and the real one as applied in the field (Borneo).

Original sampling design	Real sampling design
20 headwater catchments	approximately 14 headwater catchments, 23 sampling sites and 36 samples
random site selection from satellite images, aerial photographs and relevant maps	satellite images, but no aerial photography and no relevant maps. This leaded to no random sampling site selection, but selection according to road proximity
description of catchment features based on maps and aerial photographs	6 catchments mapped in the field, scale 1:1’000, with partial description
estimation of logging intensity from concessionnaire data sheet records on log cut	not possible from concessionnaires data sheet records, possible only for the 6 catchments mapped in field
age of logging: 0-2 years, 3-7 years, over 7 years	age of logging: 0 years; 6 months; 1 to 3 years; 4 to 5 years.
replicate twice in a year	replicate at 8 months interval, but lost of chronological sequence (age of logging) due to relogging activities
habitat assessment	yes, completed as planned
biological assessment	yes, completed as planned

There are basically two strategies for a given sampling effort. One option is to concentrate the effort on the sites and thus having less replicates at the level of the logging intensity. The second is to minimise the effort at each site in order to have more replicates. The first strategy was chosen in this study because it was decided to also collect taxa in low abundance, which are usually considered as important indicators and because the macroinvertebrate in this area was poorly known.

4.2 Materials and methods to quantify logging activities

The material that was used to quantify the logging activities at landscape scale and to follow its intensification through the time included 5 satellite images, one radar image and a few maps. The use of sensors at visible wavelengths, such as the Landsat satellites, remains a serious handicap for permanently cloudy equatorial regions, such as interior of East Kalimantan. On the study site, from 1991 up to date, despite repetitively passing over the same location every 16 days, only five Landsat images (table 10) were selected with less than 20% clouds cover: two Landsat 5 (1991 and 1997), three Landsat 7 (1999, 2000 and 2001) images. In that situation, radar images have the advantage of using microwaves which penetrate the cloud cover. The two set of stereo images acquired by CIFOR are still on process to extract a DEM model.

TABLE 10. Characteristics of the Landsat satellite images used on the study site. They are all on path 117 and row 58, with approximate coordinate of the image centre: 2°91'46''N and 116°58'49''E.

	1991 Landsat	1997 Landsat	1999 Landsat	2000 Landsat	2001 Landsat
Satellite	Landsat 5	Landsat 5	Landsat 7	Landsat 7	Landsat 7
Sensor type name	TM	TM	ETM+	ETM+	ETM+
Image capture date	20 April 1991		9 September 1999	6 May 2000	26 June 2001
Resolution	30x30m, 120x120m	30x30m, 120x120m	15x15m, 30x30m, 120x120m,	15x15m, 30x30m, 120x120m,	15x15m, 30x30m, 120x120m,
Clouds cover percentage	20%	20%	10%	10%	20%

Different spectral bands will give different responses of the same object. The usual spectral domain and related bands are: 3 bands in the visible domain, blue (B), green (G) and red (R) with wavelength respectively 0.4-0.5, 0.5-0.6 and 0.6-0.7 micrometers; 3 bands in the infrared domain, near infrared (NIR) with 0.7-2.0 micrometers, infrared (IR) with 2.0-5.0 micrometers and thermal infrared (TIR) with 8.0-15.0 micrometers. NIR and IR bands are often used in landuse, vegetation and soil management projects because of their spectral response sensibility. During daytime only, Landsat TM acquires seven spectral bands: B, G, R (band 1,2 and 3), NIR (band 4), IR (band 4 and 7) and TIR (band 6).

The sensor defines the data type. The five available satellite images were Landsat with Thematic-Mapper (TM and ETM+) sensors. Landsat TM is a polar orbital earth observation satellite with an optical sensor that observes, from a distance of 750 km, reflection of sunlight on the earth surface. This sensor cannot penetrate clouds. Cloud cover, fog and dust affect the image and have to be taken into account in the image choice. The sensor and the associated optics will define the spatial or ground resolutions of the image. The ground resolution is the size of the ground fraction observed and coded by the same pixel value in the numeric image. The current satellites resolutions range from 1 km to 1 m. The two Landsat 5 images we worked with have a 30x30 meters resolution with exception of band 6 (TIR) which has 120x120 meters. The three Landsat 7 have an eighth band with 15x15 meters resolution. The resolution does not correspond to the minimal size of visible objects. An object smaller than the resolution, such as a road on a 30 meters resolution image, will be visible because of the pixel value corresponding to the statistical mean of the various objects spectral responses.

Two different approaches are used in remote sensing to interpret a satellite image: classification and object delineation. The first approach consists in a global image classification, usually resulting in a classified image of land cover with several vegetation classes. There are different classification processes, such as: unsupervised classification, supervised classification, visual interpretation with image enhancement, segmentation mapping, neural network. The first three classification process are summarised below (Caloz & Collet, 2001).

Unsupervised classification: it is only based on image inherent statistic. It examines a large number of unknown pixels and cluster them in different classes based on image spectral information. Once the image has been classified, the classes have to be labelled as the “identity” or “theme” of a spectral class can not be initially known.

Supervised classification: it is based on training sites statistic introduced by the user. This approach needs ground knowledge. Each measurement vector is assigned to a class according to a specified decision rule. Spectral signatures are calculated as pixels mean value and standard deviation.

Visual interpretation with image enhancement: the visual aspect of an image can be enhanced to reach better information interpretation capabilities without affecting the original image content. Band histogram values and distribution form, brightness and contrast can be modified to allow the user to reach the best image visualisation aspect.

Object delineation, another approach, is essentially the detection of features such as roads, river, forest stands, etc. The method is quick and effective for small areas and is mainly applied in linear objects mapping. For large areas, the method is too time consuming. We mainly used it to digitize on screen the road network. This allowed to measure the progression of the road network through the time, on the different images, from 1991 to 1997, 1999 and 2000.

The vegetation spectral response gives valuable information about vegetation density through indices calculation. The normalised difference vegetation index NDVI (e.g. in Johnston, 1998) is widely used, but it only takes into account two wavelength bands (R, red and NIR, near infrared) for its calculation:

$$NDVI = \frac{NIR - R}{NIR + R}$$

The result image is black and white image with values ranking from -1 (low vegetation level) to +1 (high vegetation level).

Aerial photos of 1992 that covered the study area existed, but were not available. The concessionaire hired a private office to perform the required maps for the allocation of the concession. But following unresolved conflict between the two companies, these aerial photos disappeared.

Several maps at diverse scales were also gathered, but most of them were found to be inaccurate when checked in the field. In fact, the unique available map at scale 1:25’000, a contour map with river network, was poorly georeferenced and probably realised from unrectified aerial photographs. When taking coordinates with the GPS (Global Positioning System), besides the fact that the GPS position did not match with the map, this error was not constant from the north to the south of the study area. As a consequence, this unique available map revealed to be useless in the field to chose, find and subsequently locate the sampling sites.

In order to try to estimate the intensity of logging as the proportion of the catchment area which was logged, substantial time was spent at the local office from the concessionnaire in Malinau. The indonesia cutting system (see chap. Research site) worked on area of 100 ha each as cutting plot. From 1991 to 1995, these 100 ha block were symmetric quadrates, which did not respect any natural boundaries, such as streams. Afterward, these block were adapted to some of natural boundaries, but without consideration of catchment boundaries. The number of trees or the cubic meter extracted from each cutting bloc were estimated based on the work data sheet from the concessionnaire. In reality, all data sheets were prepared to fulfil the law requirements and they did not represent the real logging activities. Moreover, the boundaries of cutting blocks did not match with the headwater catchment, sometimes overlapping, sometimes two or three blocks were part of the catchment. It was difficult to calculate or even estimate any intensity of logging activities at the headwater catchment scale from the available data. Therefore, field maps were drawn, at scale 1:1’000 during field work.

In order to draw maps in the field, a 50 meter tape, compass and clinometer were used. A densiometer was used to measure the opening of the canopy. The streams were walked up from the sampling site and the upstream catchment was mapped: streams, logging roads and skid trails. The following data were measured for the streams: width, azimuth, length and slopes; and for the logging roads and skid trails: width, azimuth, length, slopes and canopy opening. This allowed to estimate the intensity of logging, but only for some catchments. The mapping was not possible for all streams, due to time available and changes occurred due to relogging activities.

4.3 Material and methods to assess ecological water quality

Ecological water quality assessment included a habitat assessment at stream reach scale and a biological assessment consisted in macroinvertebrates sampling at habitat scale (riffles and runs). Both protocols used were modified from the “Rapid Bioassessement Protocols for use in streams and rivers: periphyton, benthic, macroinvertebrates and fish” revised by Barbour et al. (1999).

4.3.1 Habitat assessment at stream reach

The biological potential is limited by the quality of the physical habitat, forming the template within which biological communities develop (Southwood, 1977). Thus, habitat assessment is defined as the evaluation of the structure of the surrounding physical habitat that influences the quality of the water resource and the condition of the resident aquatic community (Barbour et al., 1999).The habitat parameters pertinent to the assessment of habitat quality include those that characterise the stream “micro scale” habitat (e.g., estimation of embeddeddness), the “macro scale” features (e.g., channel morphology), and the riparian and bank structure features that are most often influential in affecting the other parameters.

Material used for habitat assessment included: digital thermometer (Taylor, model 9878), spherical densiometer developed and published by Lemmon (1957), conductance and pH digital tester (Beta), transparency tube, 2-meter tape, mechanical flowmeter (General Oceanics, model 2030 series) and chronometer.

At each reach, an habitat assessment was performed, including simple physico-chemistry parameters, such as temperature, pH, conductivity. No buffer area was considered. Actually, the area along the stream sides cannot be considered as buffer zone because the logging is selective (no clear cut with buffer zone along stream) and crossing the streams are very common. However, the surrounding vegetation and environmental conditions were described as much as possible.

Data sheet used in the field provided the following information and environmental variables:

- a map of the reach sampled with description of the banks and surrounding vegetation, presence of logs
- weather conditions: weather on sampling day and past 24 hours and air temperature with digital thermometer (Taylor, model 9878)

- dominant riparian vegetation described by 6 classes:

1 forest on logging activities: logged open = heavily logged
2 forest on logging activities: logged closed = lightly logged
3 pionneer vegetation (small diameter trees, Zingiberacea, Banana trees)
4 secondary vegetation (around 5 years old, pioneers trees with diameter > 10cm)
5 unlogged forest mixed with old secondary vegetation (more than 50 years old)
6 unlogged forest

- instream features: stream width and depth were measured at three different places along the reach with a 2-meter tape; percentage cover of morphology types: riffle, pool, run and cascade were visually estimated; velocity was measured with a mechanical flowmeter (General Oceanics, model 2030 series) when depth and speed allowed it. Otherwise, velocity was estimated by throwing a floating object and measuring its speed several times; canopy opening was measured with a spherical densiometer;
- dominant aquatic vegetation
- water quality: water temperature with digital thermometer (Taylor, model 9878); conductance and pH with a digital tester (Beta); transparency was measured with a transparency tube in plexiglas (equivalent of Snellen tube)
- distance to the nearest skid trails or road was estimated
- inorganic substratum components: the percentage cover of the following substratum type were visually estimated: bedrock, boulder (>256 mm), cobble (64-256 mm), gravel (2-64 mm), sand (0.06-2 mm), silt and clay together (<0.06)
- organic substratum components: the amount of detritus was observed and scored from 1 (presence) to 5 (abundant).

To complete the information taken at stream reach, organic and inorganic substratum with size between 0.25 mm to 1 mm diameter was collected. This substratum was transferred in vials, kept in alcohol and exported to Switzerland for ash-free dry mass measure (see Laboratory work thereafter).

Information about rainfall, temperature and humidity was copied from Seturan camp data, rainfall from Binhud (Inhutani II weather station in the concession) and rainfall from Malinau weather station.

Transparency measures were not used, as it did not express what was expected. It was observed in the field, that streams were reacting quickly to rain with water level raising and turbidity increasing very fast (15 minutes after the rain started, water level already raised). On the other hand, even when sampling occurred the following day after rain, sediment were already settled down and water transparent (>60 cm in Snellen tube) again. These transparency measures were too much depending on the time interval following rainy events and were judged as not reliable.

pH was measured as well, but it was decided not to incorporate the measured values in the data set. This because calibration solutions used in the field deteriorated due to heath as they could not be stored in a cool place (< 25°). Calibration measure at beginning and end of field work did not match.

4.3.2 Biological assessment on habitat type

The purpose of biological assessment is to characterise the status of water resources and to monitor trends in the condition of biological communities that are associated with anthropogenic perturbation. Several organism assemblages are used to assess the condition of biological communities; however, benthic macroinvertebrates are the most widely used (Resh et al., 1995).

Material used for biological assessment included: a Surber net with 0.25 mm mesh including a 1/10 m^2 frame to collect macroinvertebrate larvae as well as a UV light and normal light for light-trapping macroinvertebrate adults.

Benthic macroinvertebrates were collected systematically in the following way:

- at each reach to be assessed, macroinvertebrates samples were collected from a approximate 10 to 30 meters reach length. Samples were taken from riffle or run habitats to avoid oxygen limitation problems and to ensure the use of a Surber net. This net type was chosen to allow quantitative macroinvertebrate sampling.
- once the potential riffle or run was selected, the most downstream riffle or run was sampled. The Surber frame was set on bottom of the stream and the area delimited by this frame was handily disturbed (stones are brushed and removed from the frame area) with the consequence that macroinvertebrates drift into the net.
- the content of the mesh was then transferred into a plastic box filled with water. All macroinvertebrates were carefully removed with tweezers from the box, directly put into vials and preserved in 70% alcohol for further identification.
- the content of the plastic box was then filtered through two sieves, the upper one with mesh size 1 mm and the lower with mesh size 0.25 mm. The remaining macroinvertebrates picked up, the organic and inorganic substratum content of the lower sieve were transferred in bottles and preserved in 70% alcohol.
- the Surber net was carefully washed and the second Surber collected.

Following this protocol for sampling the macroinvertebrates, 3 quantitative Surber net samples of the river bottom was performed as well as 1 hour qualitative prospecting at each sampling site. The prospecting included: picking up stones in different part of the streams and collecting macroinvertebrates, looking into leaves and coarse debris packed together, brushing bedrock.

The habitat assessment and collection of macroinvertebrates samples took approximately 6 hours. Work was not possible every day due to several reasons, such as rain, unavailable car, available car but unavailable driver, unavailable field assistant, etc. The site were sampled under condition of base or near-base flow, as much as possible, waiting a few hours or days after rain.

In order to complete the information, light trapping was conducted to collect adult insects flying at sunset. Light trapping lasted two hours and was performed for all sampling occurrences in June-August 2000, but only for some in 2001.

90 dragonflies adults were caught with sweep net, to add information and to help the identification.

4.3.3 Laboratory work

All samples were brought back to the Museum of Zoology in Lausanne, Switzerland for identification as no expert could be found in Indonesia to help with the identification. Most individuals were identified at family level, except for the Ephemeroptera at genus level. Identification was based on Dudgeon's book (1999) and on all the reprint on Ephemeroptera that were available at the Museum, under the supervision of the Museum team.

In the laboratory, the substratum samples were processed to obtain the free-ash dry mass in order to estimate the organic:inorganic matter ratio. The standard processing protocol was the following (Wallace & Grubaugh, 1996):

1) the substratum was transferred in 100 ml content vials and the alcohol completed to 100 ml level. The vials were shaken and left for one hour for the substratum to deposit;
2) the levels were recorded: usually two levels were visible, the mineral substratum and the organic matter which divided in two fractions, a black and a yellowish one;
3) the content of the vial was transferred into an aluminium box and dried in the oven at 60 C° until it completely dried, which took at least 48 hours;
4) each sample was weighted on an analytical balance and its colour recorded
5) each sample was reduced to ashes in the oven at 500°C during one hour;
6) after one hour cooling, the sample was weighted it and the colour recorded. For standard coloration, the international MUNSELL Soil Colour Charts (revised edition 1994) was used.

As geological information was scarce on this area, colour from river bottom substratum was used to discriminate the different substrata. Before and after each combustion the colour of the substratum sample was recorded. Three main colours were separated after combustion, presented here by decreased order of number of samples and as well by decreased intensity of colour:

- a dominance of red (code:2.5YR5/8), named dark in the results
- a dominance of brownish yellow (code: 10YR6/6), named light in the results
- a dominance of pale pink, approaching white sand (code:5YR8/3), named pale in the results

4.4 Data Analysis

Environmental variables collected during habitat assessment were analysed in two datasets, one with all continuous variables (water temperature, conductivity, etc.) and the other with the categorical variables (vegetation, watershed, etc.). Some of the latest were log transformed for multivariate analysis.

For the qualitative data, the presence (1) or absence (0) of macroinvertebrate taxa in both the Surber and the one hour prospecting were recorded. This information of presence-absence was used to establish the list of the taxa collected, but was not statistically analysed. Statistical analyses were performed on the quantitative data, where abundance for each macroinvertebrate taxon was analysed as continuous variables, untransformed for all between-sample comparisons and diversity indices but (log +1) transformed for multivariate analysis. Quantitative data are expressed as mean number of individuals from the three Surber samples collected per sampling sites. When multiplied this mean number by ten, it becomes the density (mean number of individuals per square meters).

Descriptive statistics were used according to the data set, as it was not large enough to try any type of modelisation. The following softwares were used for statistical analysis:

- STASTISTICA software allowed to compute usual statistical data analysis (boxplot, curves, etc.), tests for differences between groups.
- ADE-4 software was used for multivariate analysis. It was developed by an hydrobiologist team in Lyon (Thioulouse et al., 1997). It is freely accessible on the internet at http://pbil.univ-lyon1.fr/ADE-4/
- EcoSim (Gotelli & Entsminger, 2001) is a computer program for null model analysis in community ecology. It was used for rarefaction calculation.

The following analysis methods were used to explore the quantitative data:

- mean values with standard deviation and standard error were calculated. They were used for between samples comparisons on all continuous variables (environmental and faunistic). Kruskal-Wallis ANOVA non parametric test on rank were tested for significant differences between groups. When significance are obtained at $p<0.05$, Mann-Whitney U-test was applied to identify between which group the difference occurred. This was applied on raw (without transformation) environmental variables and macroinvertebrates data
- rarefaction calculation (with EcoSim) was used to take into account the sampling size effect
- calculation of density, richness, diversity and evenness indices on macroinvertebrates data, for each samples
- Multivariate analysis: ordination and classification were used to explore the relationship between the “objects” (samples) and the “descriptors” (macroinvertebrate taxa, environmental variables): Principal Components Analysis on environmental variables; Correspondence Analysis on macroinvertebrate data set, followed by a cluster analysis and a Co-inertia Analysis for the co-structure.

4.4.1 Between samples comparisons

The **Kruskal-Wallis** test is a non-parametric alternative to one-way (between-groups) ANOVA. It is used to compare three or more samples, and it tests the null hypothesis that the different samples in the comparison were drawn from the same distribution or from distributions with the same median. Thus, the interpretation of the Kruskal-Wallis test is basically similar to that of the parametric one-way ANOVA, except that it is based on ranks rather than means. For more details, see Siegel (1988).

When probability that difference was significant with Kruskal-Wallis test ($p<0.05$), a **Mann-Whitney U test** was applied. It assumes that the variable under consideration was measured on at least an ordinal (rank order) scale. The interpretation of the test is essentially identical to the interpretation of the result of a t-test for independent samples, except that the U test is computed based on rank sums rather than means. The U test is the most powerful (or sensitive) non parametric alternative to the t-test for independent samples (which assumes normal data); in fact, in some instances it may offer even greater power to reject the null hypothesis than the t-test (Wonnacott & Wonnacott, 1990).

4.4.2 Abundance and diversity indices

Alpha diversity is within-area diversity, measured as the number of species occurring within an area of a given size (Huston, 1994 as cited by Magurran, 1988). Beta diversity is defined as the degree of change in (species) diversity along a transect or between habitat (Magurran, 1988).

Alpha(α) Diversity

Diversity is made of two components, the total number of species refer to as species richness and one or several indices that combine species richness with some measure of relative commonness or rareness (species evenness: how the abundance data are distributed among the species) or some other measure of the relative abundance of species.

If an entire community was exhaustively sampled, it would be easy to determine its species richness and to describe its evenness. But, in reality, it is rarely the case. The problem is that as more individuals are sampled in an assemblage, more species will be recorded and species richness rises until an asymptote is reached, meaning that the maximum number of species in the sample has been collected. But, when we sample a community, we do not know where precisely we sit on this sampling curve. The same applies to our case, for higher taxonomic level, such as genera and families.

As most species diversity indices are sensitive to the number of individuals collected, it is difficult to compare species diversity in samples of different size. Sanders (1968, as cited by Gotelli & Colwell, 2001) reasoned that the most appropriate comparison would be those that controlled for difference in number of observed individuals. In other words, he "rarefied" his samples down to a common sample size level and then compared species richness. We use the EcoSim rarefaction module (Gotelli & Entsminger, 2001). It provides a computer-sampling algorithm of rarefaction, in which a specified number of individuals are randomly drawn from a community sample. The process is repeated many times to generate a mean and a variance of species diversity. We use this rarefaction methods to compute the mean taxa richness for each of our samples.

Taxa Richness. NUMBER OF TAXA AFTER RAREFACTION becomes the most natural measure of taxa richness in our samples.

α ALPHA LOG SERIES. Extracted from the Log series abundance model, α is an index of biodiversity. It has been widely used, and remains popular (Taylor, 1978, as cited by Magurran, 1988).

As data sets containing information on number of species and on their relative abundances were gradually accumulated, it was notices that a characteristic pattern of species abundance was occurring (Fisher et al., 1943 as cited by Magurran, 1988). A species abundance distribution utilises all the information gathered in a community and is the most complete mathematical description of the data.

Although species abundance data will frequently be described by one or more of a family of distributions, diversity is usually examined in relation to four main models. These are the log normal distribution, the geometric series, the logarithmic series and MacArthur's broken stick model. When plotted on a rank/abundance graph the four models can be seen to represent a progression ranging from the geometric series where a few species are dominant with the remainder fairly uncommon, through the log series and log normal distributions where species of intermediate abundance become more and more common and ending in the conditions represented by the broken stick model in which species are as equally abundant as is ever observed in the real world (Magurran, 1988).

The log series was calculated for our macroinvertebrate data set, according to Magurran (1988). α is estimated from an iterative solution. The procedure for fitting the model is to calculate the number of species expected in each abundance class and compare that with the number of species actually observed using a goodness of fit test (χ^2).

The small number of abundant species and the large proportion of "rare" species (the class containing one individual is always the largest) predicted by the log series model suggest that, like the geometric series, it

will be most applicable in situations were one or a few factors dominate the ecology of a community (Magurran, 1988).

α log series index, according to Magurran (1988) has a good discriminant ability and is not unduly influenced by sample size. α is a satisfactory measure of diversity, is less affected by the abundances of the commonest taxa then either the Shannon or Simpson index. The only disadvantage of α is that it is based purely on S (taxa species) and N (number of individuals).

Heterogeneity index. SHANNON'S INDEX, *H*'. This index has probably been the most widely used index in community ecology. It is based on information theory (Shannon and Weaver, 1949 as cited by Magurran, 1988) and is a measure of the average degree of "uncertainty" in predicting to what species an individual chosen at random from a collection of *S* species and *N* individuals will belong. This average uncertainty increases as the number of species increases and as the distribution of individuals among the species becomes even. The Shannon index, H' is defined as:

$$H' = -\Sigma pi \ln pi \qquad \text{(EQ 1)}$$

where *H*'=0 if there is only one species in the sample and is maximum when all species are represented by the same number of individuals (even distribution on abundance). Log_2 is often used in calculating the Shannon diversity index but any log base may be adopted (Magurran, 1988).

The value of the Shannon diversity index is usually found to fall between 1.5 and 3.5 and only rarely surpasses 4.5 (Margalef, 1972 as cited by Magurran, 1988). Although as a heterogeneity measure, Shannon's index takes into account the evenness of the abundance of species (Peet, 1974 as cited by Magurran, 1988) it is possible to calculate a separate additional measure of evenness. The maximum diversity (H_{max}) which could possibly occur would be found in a situation where all species were equally abundant, in other words if $H' = H_{max} = \ln S$.

Evenness Indices. When all species in a sample are equally abundant, it seems intuitive that an evenness index should be maximum and decrease toward zero as the relative abundance of the species diverge away from evenness. Probably the most common evenness index used by ecologists is:

$$J' = \frac{H'}{\ln(S)} \qquad \text{(EQ 2)}$$

This is the familiar *J* ' of PIELOU (1975, 1977 as cited by Magurran, 1988), which express Shannon *H* ' relative to the maximum value that *H* ' can obtain when all of the species in the sample are perfectly even with one individual per species (i.e., ln *S*).

Another known evenness index:

$$E = \frac{\left(\frac{1}{\lambda}\right) - 1}{e^{H''} - 1} \qquad \text{(EQ 3)}$$

is known as the MODIFIED HILL'S RATIO. λ = Simpson index. Alatalo (1981 as cited by (Magurran, 1988) shows that E approaches zero as a single species becomes more and more dominant in a community.

Dominance. An intuitively simple dominance measure is the BERGER-PARKER INDEX D (Berger and Parker, 1970; May, 1975, both in Magurran, 1988). It has the virtue of being easy to calculate. It expresses the proportional importance of the most abundance species.

$$d = \frac{Nmax}{N} \qquad \text{(EQ 4)}$$

where *Nmax* = the number of individuals in the most abundant taxa (in our case). A decrease in the value of the index accompanies a decrease in diversity and an increase in dominance. This index is independent of S, but is influenced by sample size. May (1975 as cited by Magurran, 1988) concludes that it is one of the most satisfactory diversity measures available.

Beta (β) diversity

For quantitative data, we used distance coefficient, which are also referred to as dissimilarity coefficient. They assume a minimum value of 0 when a pair of sites are identical and have some maximum value (in some cases infinity) when the pair of sites are completely different (Ludwig & Reynolds, 1988). Between all distance measures, EUCLIDEAN DISTANCE is calculated and used to perform a cluster analysis.

$$EDjk = \sqrt{\sum (Xij - Xik)^2} \qquad \text{(EQ 5)}$$

This measure is the familiar equation for calculating the distance between two sites A_j and B_k in Euclidean space.

4.4.3 Functional feeding group

Information on the functional feeding groups were collected from diverse sources: (Dudgeon, 1999) constituted the major source information, completed with personal communication from John Morse about Asian Trichoptera. Information was also compared with the Bioassessment protocols for most of North America (Barbour et al., 1999) and Tachet et al. (2000) for Europe.

The functional feeding groups used are summarised such as represented in figure 15. :

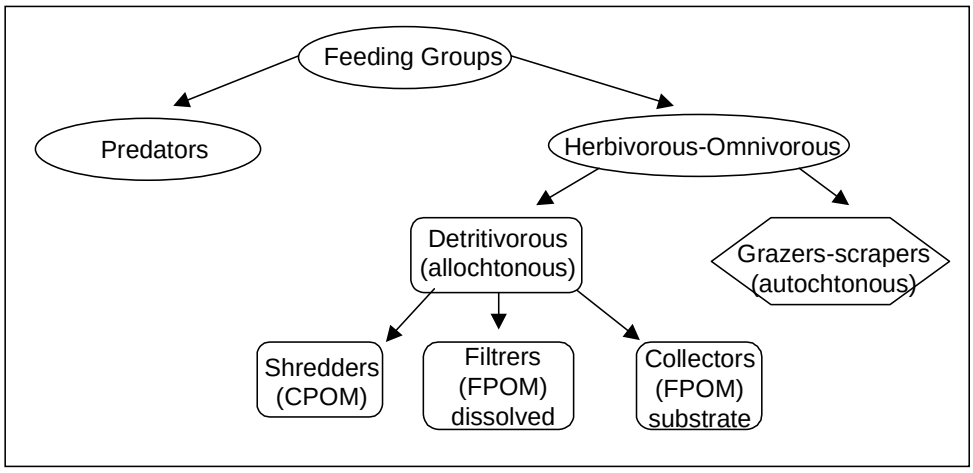


FIGURE 15. **Functional feeding groups used in our study. CPOM = Coarse Particulate Organic Matter. FPOM = Fine Particulate Organic Matter.**

4.4.4 Multivariate analysis design for the data set

For the multivariate techniques ADE-4 software was used. Date were examined with the following step by step method illustrated in figure 16 and next section describes each technique.

Environmental Data

Principal Component Analysis (PCA) using correlation matrix was used on continuous variables to separate samples into groups based on shared characteristics. All variables showing a strong departure from normality were Log transformed. The PCA graphs showed which environmental variables were mostly influential in the ordination and how they were intercorrelated.

Between-class ordination was used with categorical variables on PCA results, followed by a Monte-Carlo permutation test for significance.

Macroinvertebrate Data

The quantitative (abundance) data on the macroinvertebrates were used as departure point. Quantitative data were expressed as mean number of individuals from the 3 Surber samples collected per sampling site. When multiplied this mean number by ten, it became the mean number of individuals per square meter.

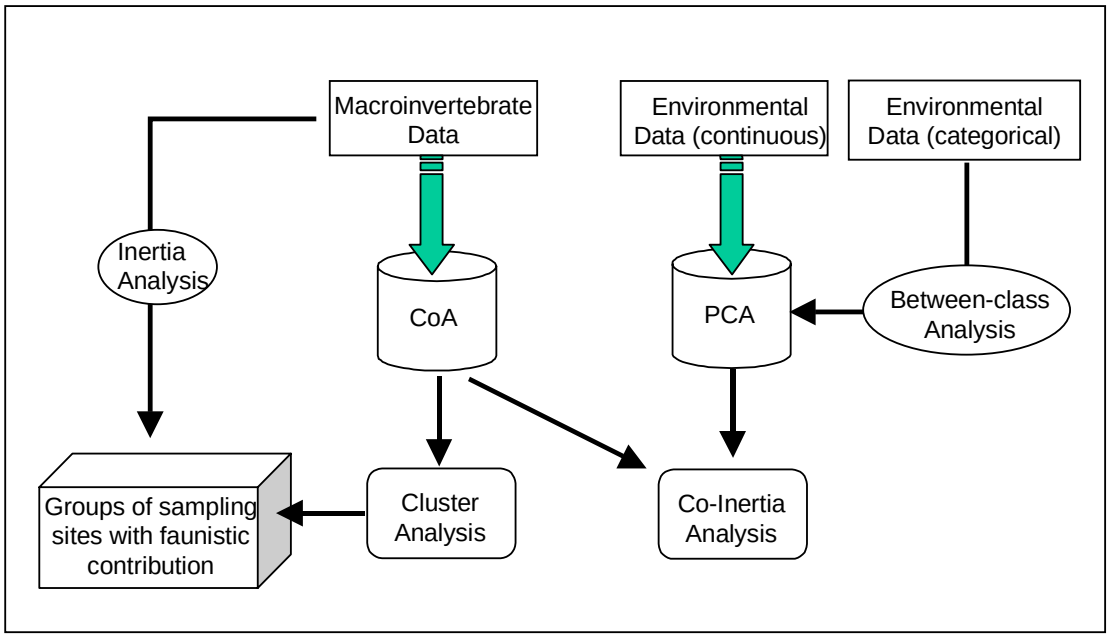


FIGURE 16. Multivariate analysis design for the data set

Macroinvertebrate data were first ordinated with a CoA (Correspondence Analysis) and then classified with a cluster Analysis. The quantitative data were (log + 1) transformed before entering the CoA, this in order to reduce the importance of large values relative to smaller values (Digby and Kempton, 1994). The graph obtained with the CoA gave the representation of the samples.

The Sample Score obtained after the CoA were used to classify the samples with a Cluster Analysis. Euclidean distance was calculated and Ward Method was chosen to compute the Cluster hierarchy. The dendrogram obtained showed the similarity/proximity of the sampling sites. Once the level of dichotomial separation was chosen, an Inertia Analysis was performed to calculate the contribution for each taxa to the groups designed by the chosen level. The quantitative data from the starting point were taken back and the contribution for each taxa was added. This helped to build the faunistic legend for each of the group defined by the cluster analysis. Once these faunistic groups were defined, they were used as grouping variables for the environmental variables.

A Co-inertia analysis was run to observe how the environmental variables were related to the macroinvertebrates data.

4.4.5 Multivariate Exploratory Techniques

Gower (1984 as cited by Legendre & Legendre, 1998) pointed out that the term “ordination”, used in multivariate statistics, actually came from ecology where it referred to the representation of objects (sites, location, samples, etc.) as points along one or several axes of reference. Ordination is a set of techniques in which samples are arranged in relation to one or more coordinate axes, such that their relative position to the axes and to each other provides maximum information about their ecological similarities. The aim of ordination is to simplify and condense massive data sets, so that ecological relationships emerge (Ludwig & Reynolds, 1988). Ordination in reduced space is often referred to as “factor (or inertia) analysis” since it is based on the extraction of the eigenvectors or “factors” of the association matrix (Legendre & Legendre, 1998).

Ordination is a method of partitioning a resemblance matrix into a set of orthogonal (perpendicular) axes or components. Each axis obtained corresponds to an eigenvalue of the matrix. The eigenvalue is the variance accounted for by that axis. They are extracted in descending order of magnitude, such that the corresponding axes (components) represent successively greater to lesser amounts of variation in the matrix. Hence, the first few axes, upon which the samples will be positioned, will represent the largest percentage of the total variation that can be explained. The result is a reduced coordinate system that provides information about the ecological resemblances between samples (Ludwig & Reynolds, 1988). For the detail of procedures and mathematics for all multivariate techniques we used, see Legendre & Legendre (1998) and Ludwig & Reynolds (1988).

Amongst the whole range of ordination methods, the Principal Components Analysis was used for environmental variables and the Correspondence Analysis for the fauna dataset (abundance of taxa).

Principal Components Analysis (PCA)

PCA has to be used with quantitative descriptors only, for which valid estimates of the covariance or correlations may be obtained (Legendre & Legendre, 1998).The original data are centred or normalised transformed and the eigenvalues and vectors are extracted from a correlation matrix to be computed into samples coordinates or scores.

In order to analyse the environmental variables of the sampling sites, the data set was explored with a multivariate technique. Because environmental variables are quantitative and are not expressed in the same units, a normalised Principal Components Analysis (PCA) is used to analyse this data set. Based on a preliminary exploratory analysis, some of the variables were transformed. The PCA is then processed with the following continuous environmental variables: water temperature (°C), flow velocity (m/s), stream depth (m), Organic Matter ratio (%), stream width (m) Log transformed, canopy opening (%) Log transformed and fine substrate (< 6 cm) Log transformed.

Between-class ordination

One simple way to compare the efficiency of partitions of a data set is to measure the ratio of the inertia (i.e. of information) explained by this partition to the total inertia described in the ordination of the data. This procedure is known as «between-class ordination» where one describes the part of the inertia of a data set that is explained by an external categorical variable (Dolédec and Chessel, 1987). We use this between-class ordination to explain the part of the inertia of the PCA that can be explained by our environmental categorical variables. To test the statistical significance of this between-class ordination, a 1000 random Monte-Carlo permutation test is used.

Monte-Carlo permutation test

Named after the casino of the principality of Monaco, Monte-Carlo methods use random number to study either real data sets or the behaviour of statistical methods through simulations. Permutation tests are Monte Carlo methods because they use random numbers to randomly permute data.

The null hypothesis is rejected at the decided level α if the observed value of the test statistic in the original sample falls out of the intervals given by the α /2 and (1- α /2) empirical percentiles of the frequency distribution of the test statistic obtained with the permutations (adapted from Belluzo).

Correspondence Analysis (CoA)

A number of methods for analysing taxa-by-sample are available (see e.g Thioulouse et al., 1997). Nevertheless, multivariate analysis such as Correspondence Analysis (CoA) is often used because a “corresponding” sample and taxa ordination are obtained simultaneously, allowing examination of interrelationships between samples and taxa in a single analysis. In fact, the most common application of CoA in ecology is the analysis of species data (presence-absence or abundance values) at different sampling sites.

CoA can be viewed as a variant of PCA (Pielou, 1984 as cited by Ludwig & Reynolds, 1988). But it differs in two ways: the original data are double transformed and eigenanalysis is used to produce corresponding species and samples ordination based on Chi-square distance. In CoA, the species ordination coordinates are averages of the samples ordination scores and, vice et versa, the samples ordination coordinates are averages of the species ordination correlations (Gauch, 1982 as cited by Ludwig & Reynolds, 1988).

To process the CoA with the macroinvertebrate data set, the mean abundance of the taxa were log (x+1) transformed.

Cluster Analysis

In community classification, the objective is to reduce the data matrix X_{SN}, S rows (taxa) and N columns (samples) into g < N “homogeneous” groups or clusters, that is, the samples within each of the g clusters are more similar to one another than are the samples between clusters (Green, 1980 as cited by Ludwig & Reynolds, 1988). Clustering algorithms have been developed using a wide range of conceptual models and for studying a variety of problems. Ward’s method was used.

Ward’s method is part of hierarchical agglomerative clustering methods. Ward’s minimum variance method is related to the centroid methods in that it also leads to a geometric representation in which cluster centroids play an important role. To form clusters, the method minimizes an “objective function” which is, in this case, the same “square error” criterion as that used in multivariate analysis of variance. At the beginning of the procedure, each objects is in a cluster of its own, so that the distance of an object to its cluster’s centroid is 0; hence, the sum of all these distances is also 0. As clusters form, the centroids move away from actual object coordinates and the sums of the squared distances from the objects to the centroids

increase. At each clustering step, Ward's method finds the pair of objects or clusters whose fusion increases as little as possible the sum, over all objects, of the squared distances between objects and cluster centroids. The distance of object to the centroid of its cluster is computed using the Euclidean distance. For more details on Ward's method, see Legendre & Legendre (1998), from which the latter explanation has been extracted.

Contributions from the taxa are calculated on the basis of their relative abundance in each cluster group. Following Roux (1991), the contribution (CV(j,p) of each taxon (j) to each sample cluster (p) is calculated as:

$$(CV_{(j,p)})=((Z_{pj}-Z_j)^2 / \Sigma_j(Z_{pj}-Z_j)^2) \quad \textbf{(EQ 6)}$$

with Zpj= average of taxon j in cluster p and Zj= overall average of taxon j. The obtained value "contribution of variables to clusters" are summed up to 100 for each cluster group. A positive sign is given to the contribution when Zpj>Zj, indicating that the mean taxa in the cluster is superior to the mean taxa on all samples and a negative sign is given to the contribution when Zpj<Zj, indicating that the mean taxa in the cluster is inferior to the mean taxa on all samples.

Co-inertia Analysis

Co-inertia analysis is a two-table ordination methods, as is the canonical correspondence analysis of Ter Braak (1986,1987, as cited by Doledec & Chessel, 1994) or canonical correlation analysis (Gittins, 1985 as cited by Doledec & Chessel, 1994). In canonical correspondence analysis, a small number of environmental variables is required to predict the faunistic structure. In canonical correlation analysis, the number of species (or taxa) and the number of environmental variables must be much lower than the number of samples.

Co-inertia analysis comes as an extension to the approach by Tucker (1985, as cited by Doledec & Chessel, 1994). It allows the description of the common structure between two data tables. It works on a covariance matrix (species x environment) and enables various standard analysis, such as Correspondence Analysis and Principal Components Analysis to be connected. It is the only way to search for species-environment relationships when many variables are taken in few samples (Doledec & Chessel, 1994).

CHAPTER 5

Assessment of logging activities in the studied landscape

This chapter compiles the data gathered on the study area extended at landscape scale which encompasses part of the Malinau watershed, as illustrated in figure 14 on page 42. As already mentioned (Chapter 1), the rationale for relating ecological water quality of streams and forest quality is that streams are a reflection of the watersheds they drain (Hynes, 1975). The objective of this chapter was to assess logging activities in a tropical forest, at landscape scale. The following hypothesis was proposed:

> **Hypothesis: logging activities change the forest quality in the studied landscape**

The chapter is divided in three parts. In the first part, vegetation classification from satellite images is examined. This in order to distinguish between unlogged and logged forest at various intensities. In the second part, the logging roads from five satellite images were measured to examine logging intensification through the time (1991-2001). In the third part, skidtrails were measured to assess logging intensity upstream six sampling sites. The chapter ends up with a discussion on the observations made.

5.1 Vegetation classification

Remote sensed data, as satellite and aerial images, can be valuable sources of accurate and up-to-date information. They are increasingly used for diverse purposes in landscape study. For a long time, low spectral and spatial resolutions and high costs limited their applications. This is not the case any more.

Satellite images can be visualised in black and white or in colour mode. The colour mode is a combination of three bands, attributed respectively to the Red, Green and Blue colour layers of the media (screen, printer,..). The band combination RGB 453 was used in this study.

Figure 17 presents all five satellites images side by side to illustrate clouds cover and to highlight the difference in false coloration despite the use of same bands RGB 453. The 1991 image is from far of best quality among the four images. Moreover, it gives the original status before logging activities started in the studied area. The 1997 image was affected by striping. The corresponding scanning line default is generally the result of sensor drift, diagnose by a regular and periodic change in image contrast between adjacent lines. It indicates a decreasing quality of the sensor for that band (Landsat TM dated 1984). This striping effect is difficult to correct. In addition, clouds cover an important part of the study area. Both 1999, 2000 and 2001 images are of good quality but covered by clouds on the research area. The 2000 image is moreover affected by fog on most of it.

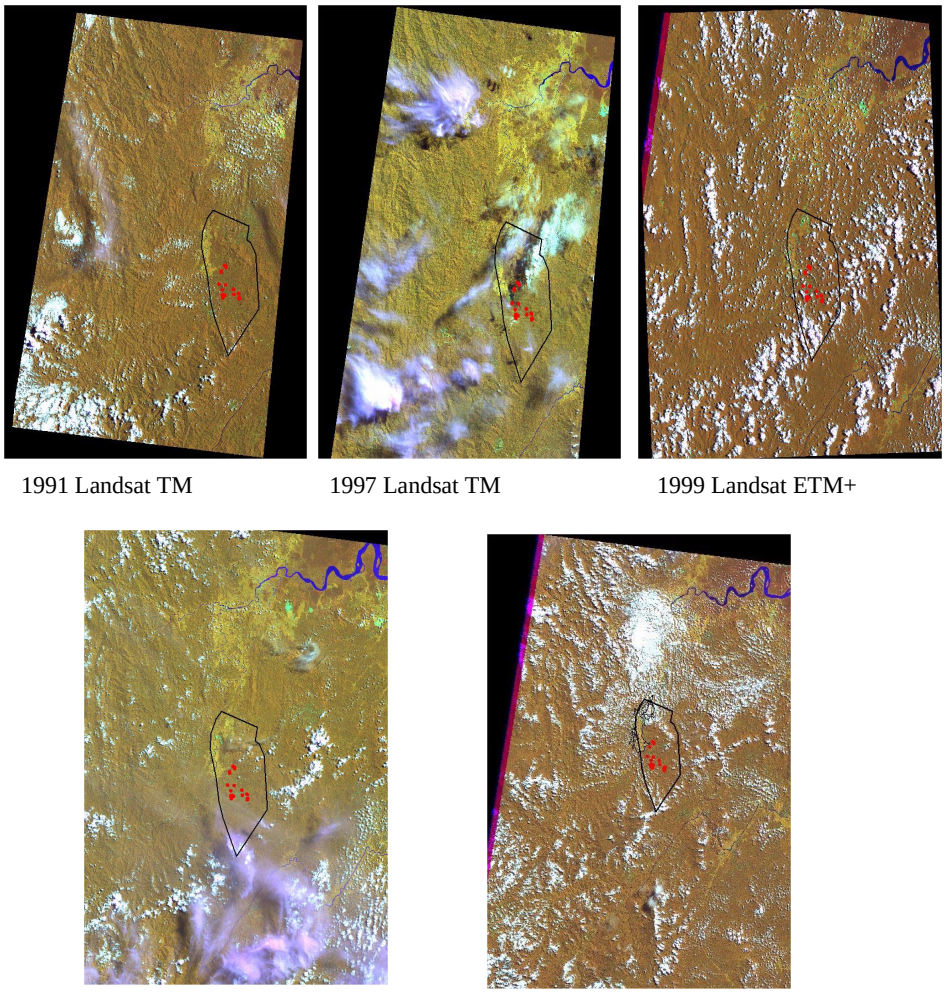
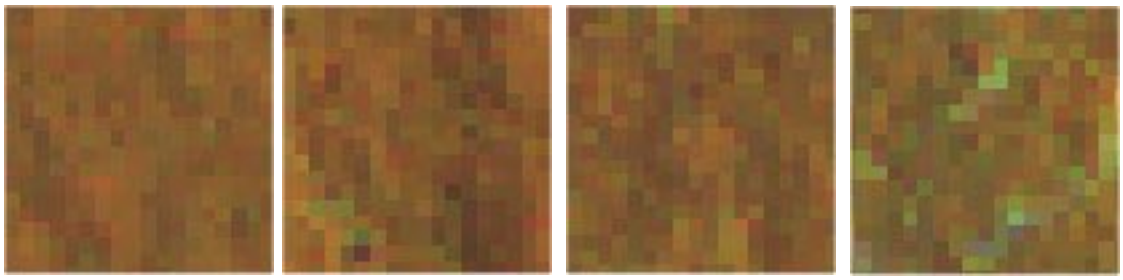


FIGURE 17. The five satellites images with Inhutani II concession delineated in black and location of samples in red. Same band combination RGB 453 are used for all images.

Image classification is usually used to separate vegetation classes such as unlogged forest from logged forest with different logging intensity and number of years after logging. Before going into complex classification processes, first preliminary tests for image classification were performed by a specialist at LaSIG (laboratory of Geographical Information System, EPFL). He performed unsupervised classification, as

well as supervised classification. Unsupervised classification did not give any results. The clusters were statistically too close to one another so that different forest classes could not be distinguished. Supervised classification did not bring better results. Thus, it was not possible to assess the impact of the logging activities on the forest quality with a vegetation classification based on forest classes (unlogged versus logged at various intensity). Some of the main problems encountered in the study area are explained hereafter.

Correspondence between scale resolution of the image and disturbance scale. The optimal scale of visualisation and interpretation is a compromise between avoiding blocking effect (high zoom) and having too many details. The recommended scale for a 30x30m resolution is between 1:100'000 and 1:400'000 depending on the printer (130 or 300 dpi). Figure 20 illustrates scale 1:50'000 which already has a blocking effect, whereas Figure 21 to 9 show images at scale 1:200'000. The image resolution was 30x30m (1 pixel) for most bands. In order to detect and quantify disturbances in the forest cover, the canopy opening should be more or less 30 m large and contiguous to form identified patches from at least 3x3 pixels. As Indonesia applied a selective cutting system, the disturbance scale due to harvesting trees did not match the image scale. In fact, a mixed mosaic of pixel which did not have a specific spectral signature allowing to create a forest class (fig 18) was obtained. The forest cover in this area has a fine patchy but homogeneous structure. In figures 21 to 25 open area can be distinguished from forest cover, but inside the forest cover, only the very fresh logged area can be recognised, because of logging roads and skidtrails presence.

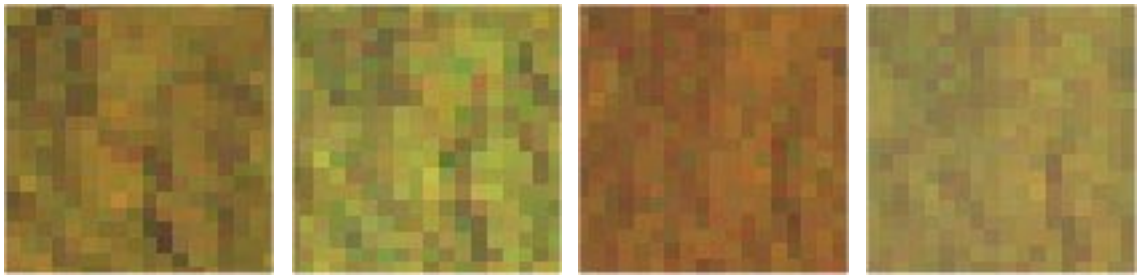


unlogged | logged in 1995 | logged in 1997 | logged in 1999

FIGURE 18. **All frame are taken from 1999 Landsat image at scale 1:20'000, with pixel resolution of 30mx30m.**

Relief. On the five images (figures 21 to 9), the area surrounding the Rian and Seturan watersheds is predominantly hilly to mountainous, with a plain appearing more or less flat. But the image did not give an appropriate idea of the reality. In chapter "Study area", some of the land system unit characterised by their hillslope length were described. Most of the plain area are in fact belonging to a landsystem unit characterised by hillslopes less than 50 meters length. Covered by forest, this soil undulation is not visible on the image. This introduced a bias for detecting the logging activities. As a matter of fact, the size of canopy opening following tree cutting is smaller from vertical view when considering slope area compared to flat ones. The dense hilly relief also introduced shadows problems which make it difficult to create vegetation classes in the forest.

Comparison between satellite images. Spectral differences between images unrelated to the sensor target can be caused by degradation of the satellite signal caused by clouds, haze, dust or other attenuating factors, as well as differences in viewing geometry (solar angle, solar azimuth and satellite zenith). Figure 19 highlights the different spectral response obtained from one image compared to the others, despite the use of the same band combination RGB 453. The same hilly area was selected in each satellite image. This means that even if some vegetation classes could be distinguished by their spectral signature for one image, they could not be applied on another one without complex transformation.



1991 Landsat 1997 Landsat 1999 Landsat 2000 Landsat

FIGURE 19. Same hilly area from all four images at same location, covered by undisturbed rainforest. Scale 1:20'000, size 100x100 pizels, pixel resolution 30mx30m. Bands 543.

Clouds cover. Another important factor was the proportion of the image covered by clouds and their location. On the five images (figure 17), the study area was partially covered by clouds, but each time on different location. As a consequence, almost no area could be followed and compared through the time.

NDVI vegetation index indicating the biomass production was used. It did not give any results as the index saturated because of high vegetation cover. This index, widely applied and easily interpretable is mainly used in semi-arid zones with contrasted land cover.

5.2 Assessment of logging roads

Available maps at diverse scales had been manually digitised by several poorly trained persons. As a result, some maps had digitised several time by different persons, so that the layers obtained in Arcview GIS did not match with each other and could not be superposed on the satellite images. An example is illustrated in figure 20. Combination RGB 543 allowed to recognise rivers in dark grey, logging roads in light-blue, forest vegetation in brownish-green versus open areas (field, villages) in ocre-blue.

As it was too difficult to transform the digitised maps to make them fit the satellite image, it was proceeded in the reverse way. The satellite image was pivoted and twisted to fit the digitised layers, such as presented in figures 21 to 25. The resulting images did not correspond any more either to the longitude-latitude position or to the UTM projection. Thus, coordinates were not valid any more, but this allowed to superpose the river system layer digitised from the map and the logging roads network digitised from the satellite images.

The following features, such as river system, logging roads, open area and coal mine are described thereafter from one image to the other, and are summarised in table 11.

The **river system** was based on the layer digitised from the 1:25'000 contour map produced by Inhutani II. On the satellite images, some of the sampling sites on streams less than 6 meters width, were visible, but not all. The vegetation covered them to a larger extend. Because of the area being undulated and hilly, the river network was very dense. On the satellite images, the river system is often crossed by logging road. On the ground, this correspond to bridges, but not always. In fact, most of the time, the logging roads were poorly built and drained. Thus, many ponds were observed in the field on each side of the road. Their size fluctuated with rain which explained that they could not be located on the images. The climate makes it

difficult to maintain the roads in operational condition (for heavy trucks to transport the logs) and several times, part of the roads were destroyed following storms.

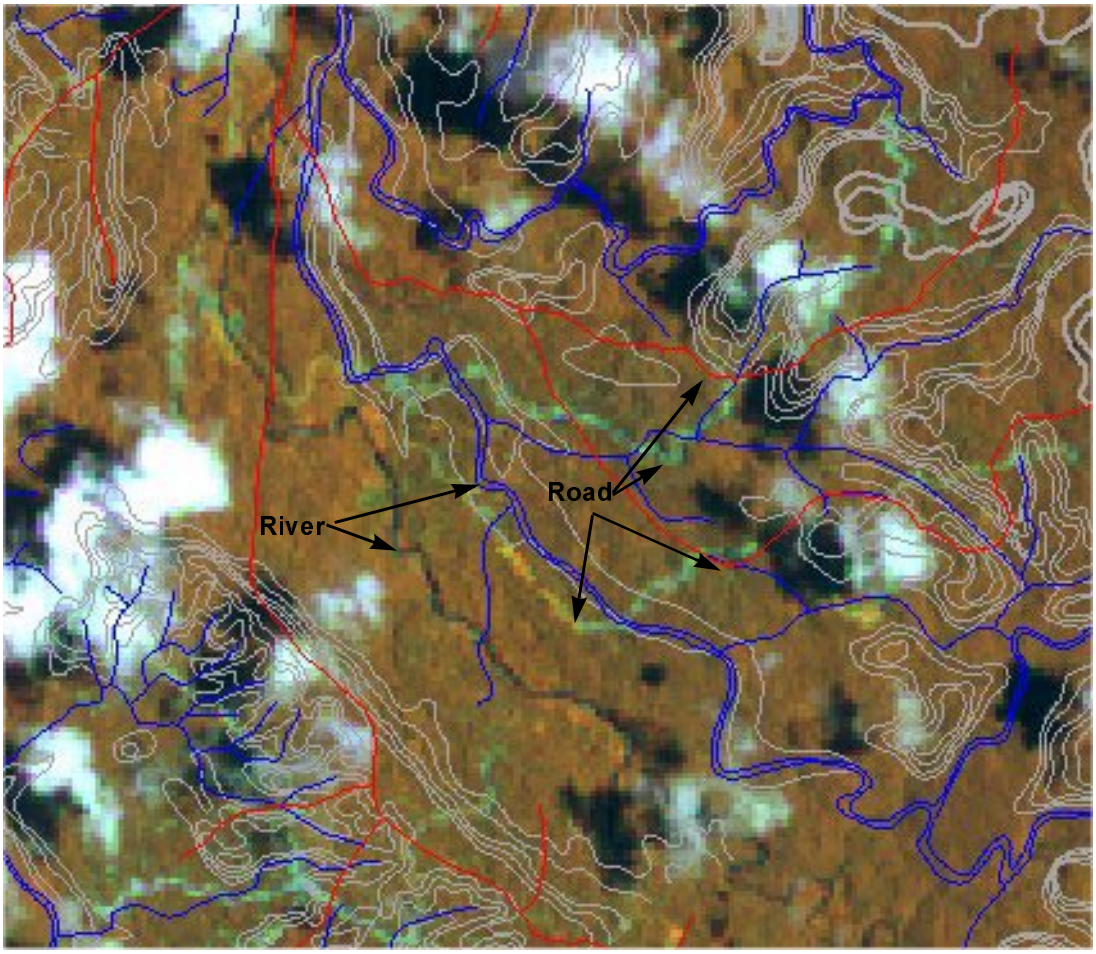


FIGURE 20. 1999 Landsat image with road layer in red, river layer in blue and contour layer in grey. Approximate scale 1:50'000.

TABLE 11. Features measured on the five Landsat images on an area covering approximately 2000 square kilometers. Number in bracket indicate the increase in value, from one year to the other.

	1991	1997	1999	2000	2001
Logging roads inside the concession (km)	117	182 (+65)	217 (+35)	222 (+5)	257 (+35)
Logging roads in neighbouring concessions (km)	74	339 (+265)	454 (+115)	475 (+21)	491 (+16)
Open area (km2)	56	57.5 (+1.5)	83 (+25.5)	85 (+2)	86 (+1)
Coal mine (km2) inside the concession	0	0.37 (+0.37)	1.1 (+0.73)	1.25 (0.15)	1.5 (+0.25)

The **logging roads** were digitised in each of the five satellite image in order to follow their intensification/ progression, inside Inhutani II concession and in the neighbouring concessions (table 11). The whole digitised area covered approximately 2000 km^2 (40x50 km) and corresponded to what appears on figure 21 to 25. Prior to the start of logging activities in that area, the main transportation mean to reach Long Loreh and Langap villages was by boat on the Malinau river. The river system in the concession could not be used for logs transport because of insufficient and irregular amount of water. This means that roads in the study area can only be attributed to the logging activities.

In **1991** (fig. 21) the logging roads covered 82 km inside the northern part of the concession and 35 km in the southern part. The road occurring in the south did not belong to Inhutani II timber concession, despite their being inside the boundaries. The approximate delineation of the concession was probably wrong, but it was not uncommon for the concessionnaire not to respect the boundaries of its allocated area. This was clearly observed in the north of the concession where they logged outside the boundaries. The main reason is the difficulty involve in orientating oneself in the field. **1997** image (fig. 22): within six years time, progression of the road is important, even outside the concession on the south-west side where the relief is more mountainous. **1999** image (fig. 23): newly built road reached 35 km more, inside the concession within two years. It can be noticed that in the north-east part of the concession, it was difficult to distinguish the road network built in 1991. **2000** image (fig. 24): only 5 more kilometers have been built within 8 months, probably due to the political decentralisation process, which brought changes in the management of the Inhutani II concession. These is similar to road building outside the concession, which totalled only 21 new km. **2001** image (fig. 25). Several new concessionnaire called by local population arrived inside the boundary of Inhutani II concession to log on small scale permit (100 ha). As a result, 35 new kilometers were built within 1 year and the area logged looked more intensively harvested than on the previous images (no quantification). Outside the concession, the road construction was similar to 2000, approximately 16 new km.

Open areas were located around the main villages of Long Loreh and Langap. These open area were used for agriculture under the slash-and-burn system. A coarse approximation of their size revealed that from 1991 to 1997, its boundaries did not change much, from 56 km^2 to 57.5 km^2. However, from 1997 to 1999, the open areas increased up to 83 km^2 and remained constant from 1999 to 2000, as well as from 2000 to 2001. Green patches occurring within these open areas probably indicated recently burnt field for cultivation. Open area might be related to the coal mine expansion. Many outsider workers arrived, which increased the demand for food.

The **open-air coal mine** did not appear on the 1991 image, despite the fact that it officially existed before 1990. It appeared on the 1997 satellite images, where its size was around 0.37 km^2 and increase from 1997 to 1999 up to 1.1 km^2 to reach 1.25 km^2 in 2000. In 2001 the extension continued south of the main coal mine. Old exploited sections of the mine acted as sedimentation basins for the particles to deposit before the water entered the Malinau river. But, each heavy rain made the basin overflowed and all the deposits drained by the water were carried down to the river.

Since the company dug the coal, Long Loreh villager had to avoid using the water from the streams for their domestic use (drinking water, bathing, fishing..). Many conflicts arose between the villagers and the company. The latter had to install wells and pumps to bring clean water from the Sidi mountain.

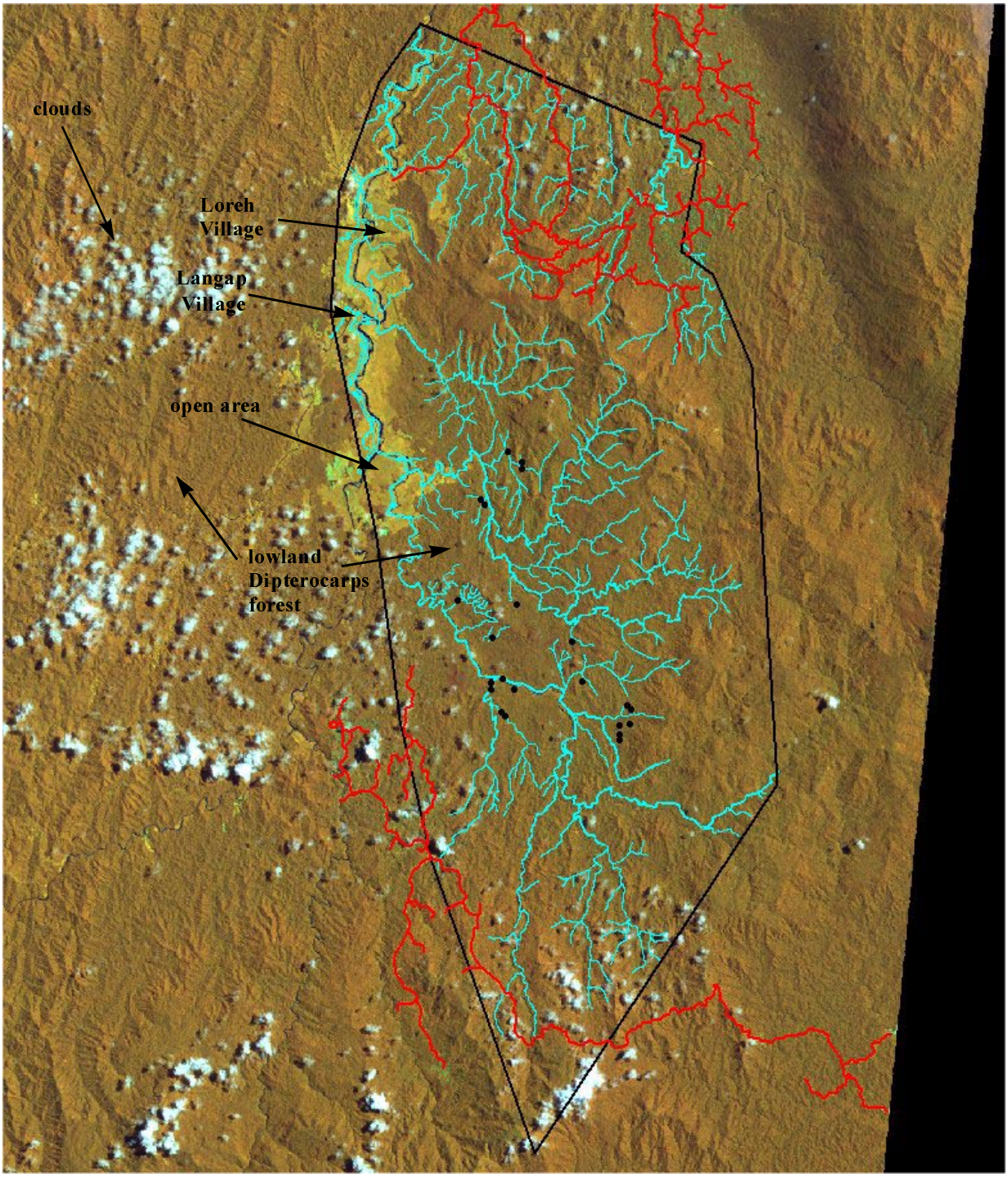


FIGURE 21. 1991 Landsat TM image with approximate delineation of Inhutani II concession, river network in blue and logging roads in red. Back dots indicate approximate localisation of sampling sites. Scale: 1:260'000

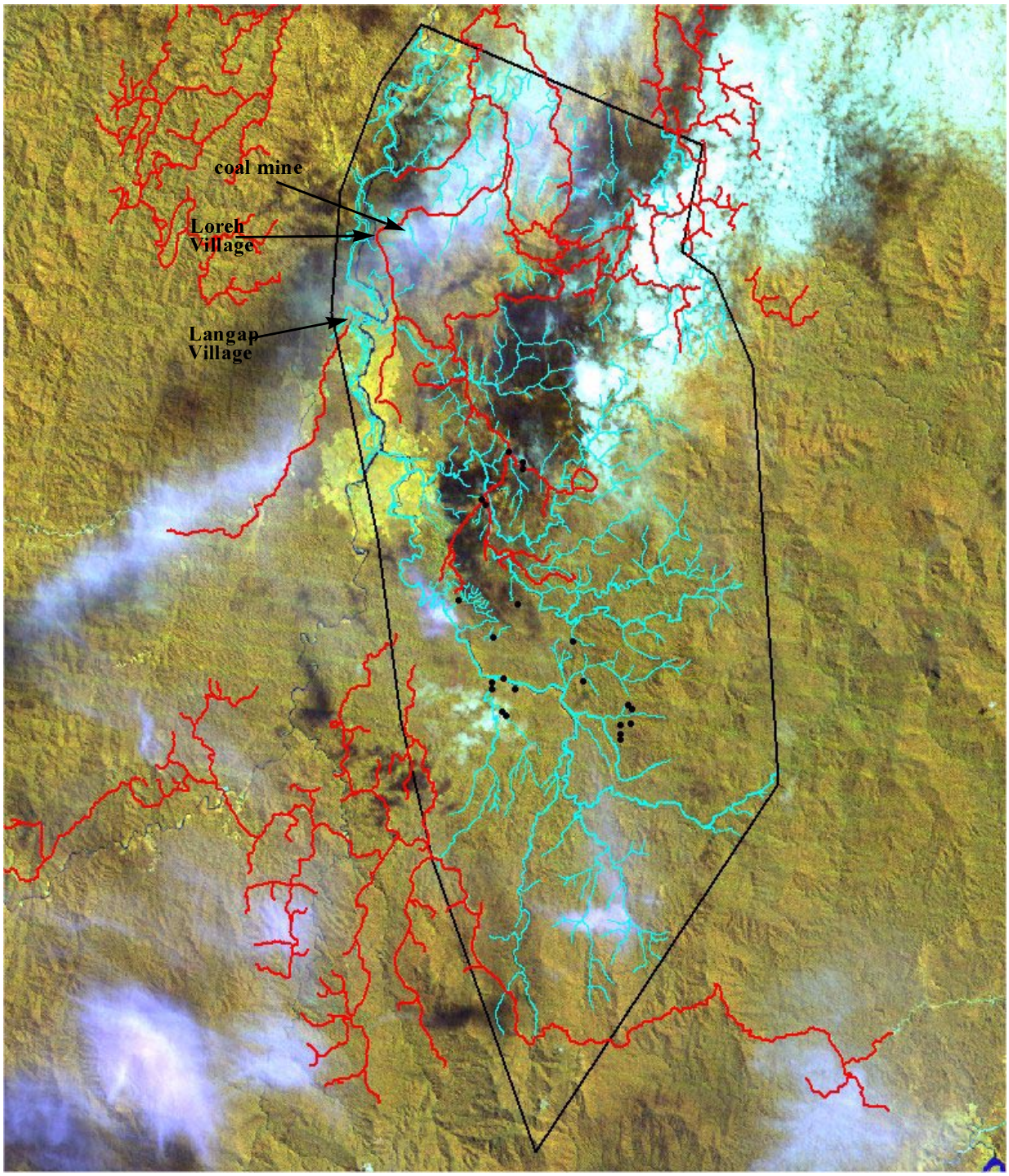


FIGURE 22. 1997 Landsat TM image with approximate delineation of Inhutani II concession, river network in blue and logging roads in red. Black dots indicate approximate localisation of sampling sites. Scale: 1:260'000

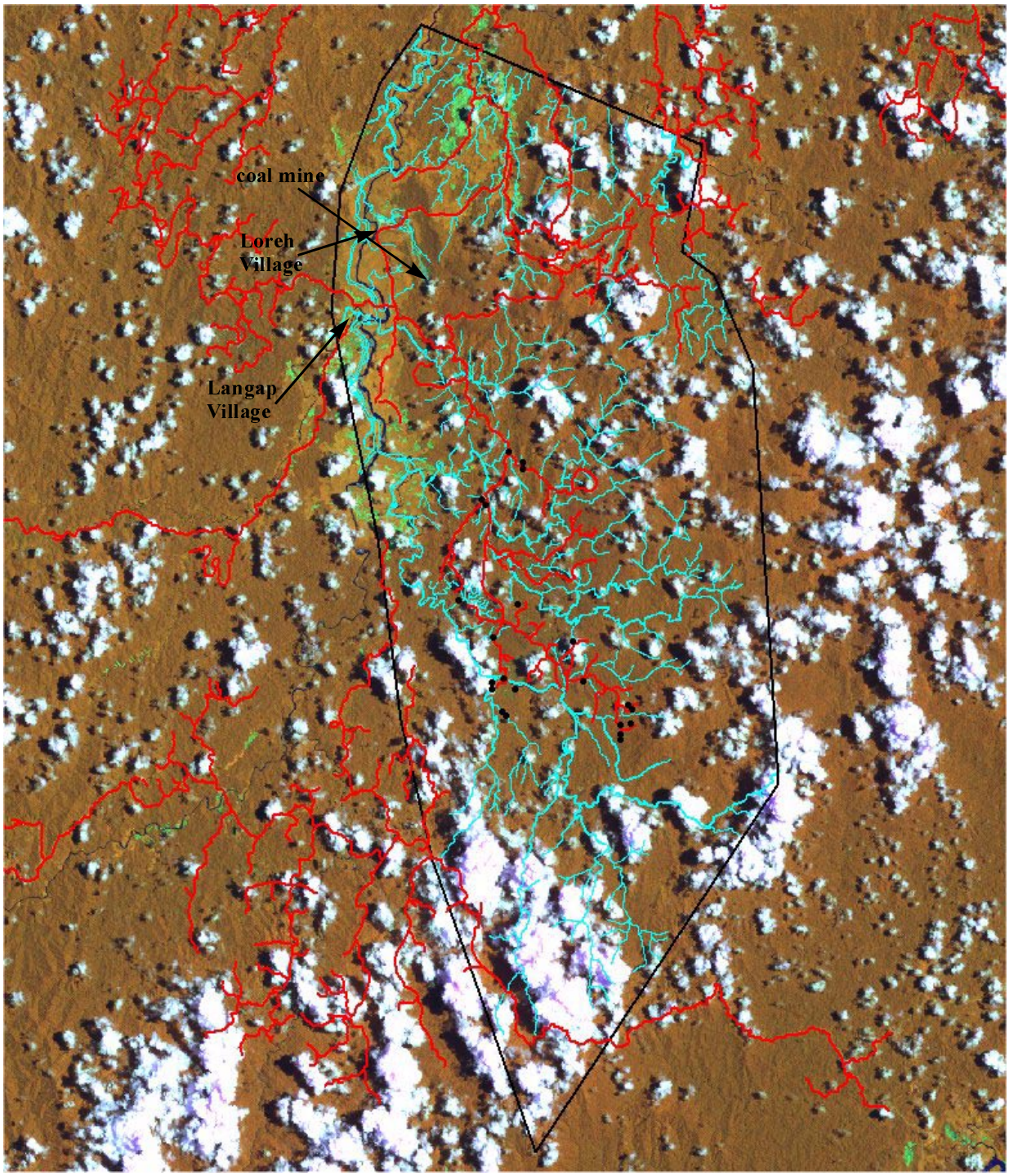


FIGURE 23. 1999 Landsat TM image with approximate delineation of Inhutani II concession, river network in blue and logging roads in red. Black dots indicate approximate localisation of sampling sites. Scale: 1:260'000

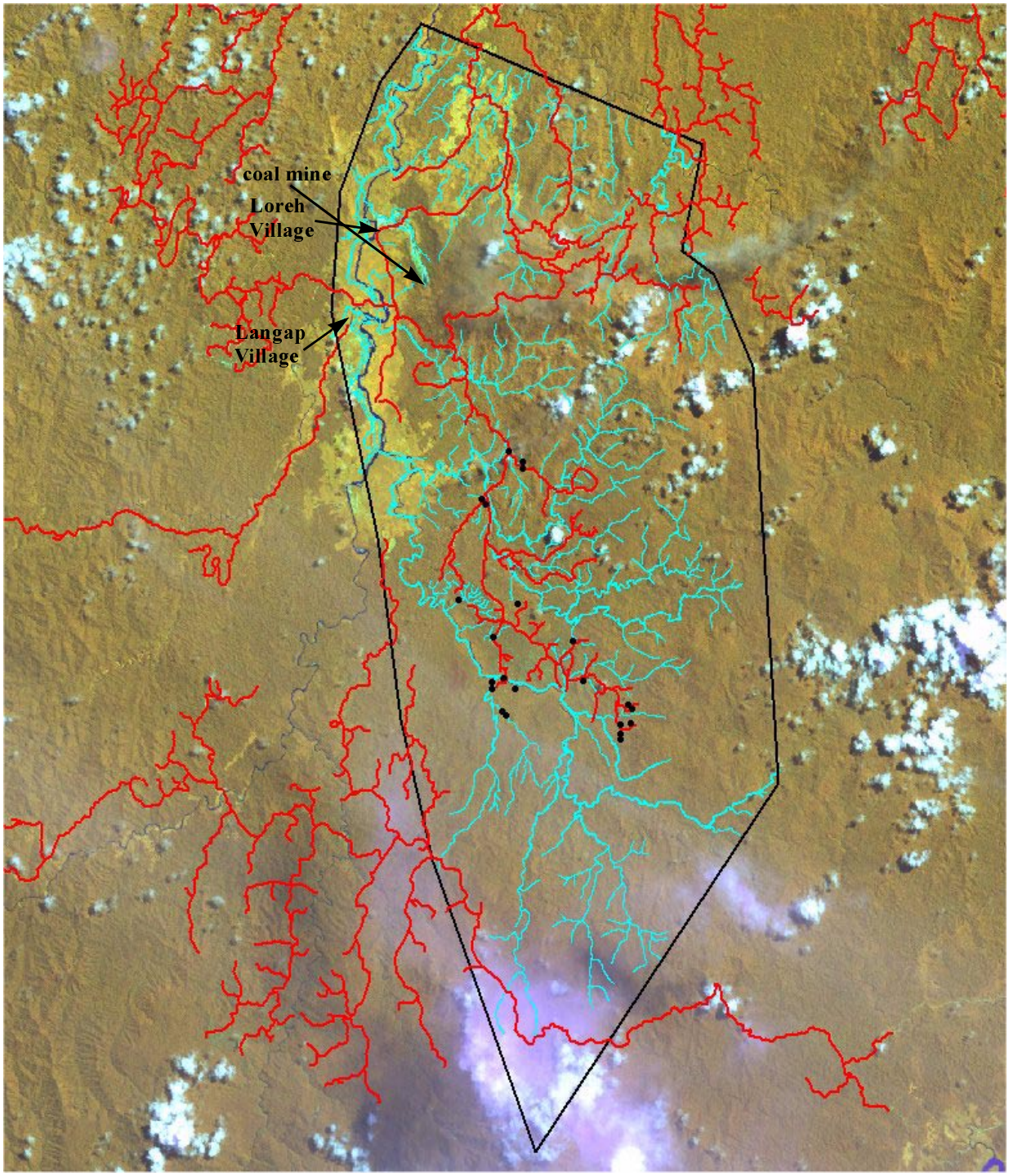


FIGURE 24. 2000 Landsat TM image with approximate delineation of Inhutani II concession, river network in blue and logging roads in red. Black dots indicate approximate localisation of sampling sites. Scale: 1:260'000

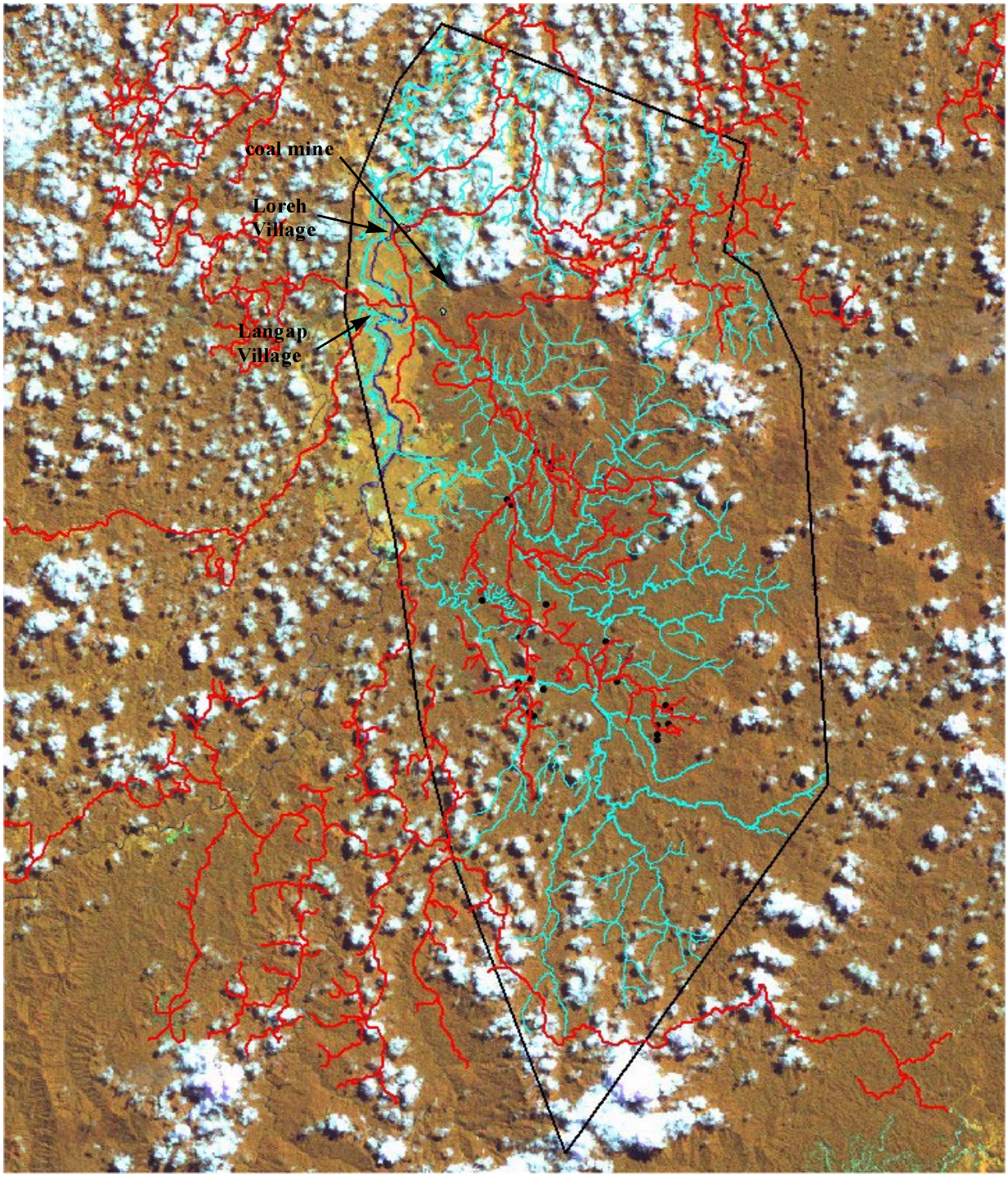


FIGURE 25. 2001 Landsat TM image with approximate delineation of Inhutani II concession, river network in blue and logging roads in red. Black dots indicate approximate localisation of sampling sites. Scale: 1:260'000

5.3 Assessment of skidtrails

Five small catchments upstream the sampling sites were mapped during fieldwork in June-August 2000. From the sampling site, the stream were followed upstream to map the stream system and the catchment. In the second step, within the delineated catchment, the skidtrails were mapped. The sixth catchments where the Reduced Impact Logging was performed, was mapped by Inhutani II as part of the RIL procedure (sampling site 11 RIL in table 12). Mapping activities continued during the second fieldwork in March-May 2001. Because of all changes due to relogging activities, three out of the five catchments mapped in 2000 were relogged in 2001. The new skidtrails were recorded.

TABLE 12. Streams length and estimated logged area ((skidtrails length + logging road length)* 40 m) for each catchment mapped.

	sampling site 11 RIL	sampling site 9	sampling site 10	sampling site 2	sampling site 1.2	sampling site 1.1
Area (m^2)	532’905	994’136	568’768	532’106	379’170	517’400
Streams length (m):						
1rst order	2’717	2’115	2’135	1’526	1’873	1’566
2nd order	739	1’920	1’573	1’789	861	817
3rd order	1’054	1’139	217	596	621	1’420
4th order			1’148	339	662	
Total stream length (m)	4’510	5’174	5’073	4’250	4’016	3’803
Logging activities up to 2000:						
logging road	1’920	1’016		2’073	636	947
skidtrails	6’070	13’213	4’452	2’772	655	2’587
New skidtrails in 2001				595	563[a]	761
estimated logged area (m^2)	319’600	569’160	178’080	217’600	74’160	171’800
estimated % of the area logged	60%	57%	31%	41%	20%	33%

a. of which 235 m are inside the riverbed

Table 12 gives the following features for each catchment mapped: estimated area covered by the catchment, stream length for each of the stream order, as well as length for logging road and skidtrails encountered. According to the literature, total disturbed area can be estimated in average at 15 meters each side of a skidtrails or logging road. An average number of 20 meters each side was decide, including the tractor path width (usually between 5 to 10 meters width). This enabled to estimate logging intensity in percentage of each catchment area.

5.4 Discussion

Remote sensing has considerable potential for the study of forest change, including subtle modifications associated with degradation or recovery. It is the only way of monitoring forests at regional to global scales (Foody et al., 2000). This could be of particular interest for regions such as our study site where access is difficult and maps inaccurate. But unfortunately application of remote sensing in tropical forest is problematic, especially for vegetation classification. Many of the approaches that have been used were developed for applications in temperate environments and are often inappropriate for the tropics. Moreover, efforts to monitor change in broad-scale vegetation pattern using satellite-based remote sensing have largely focused on the presence/absence of vegetation due to deforestation/afforestation, natural distur-

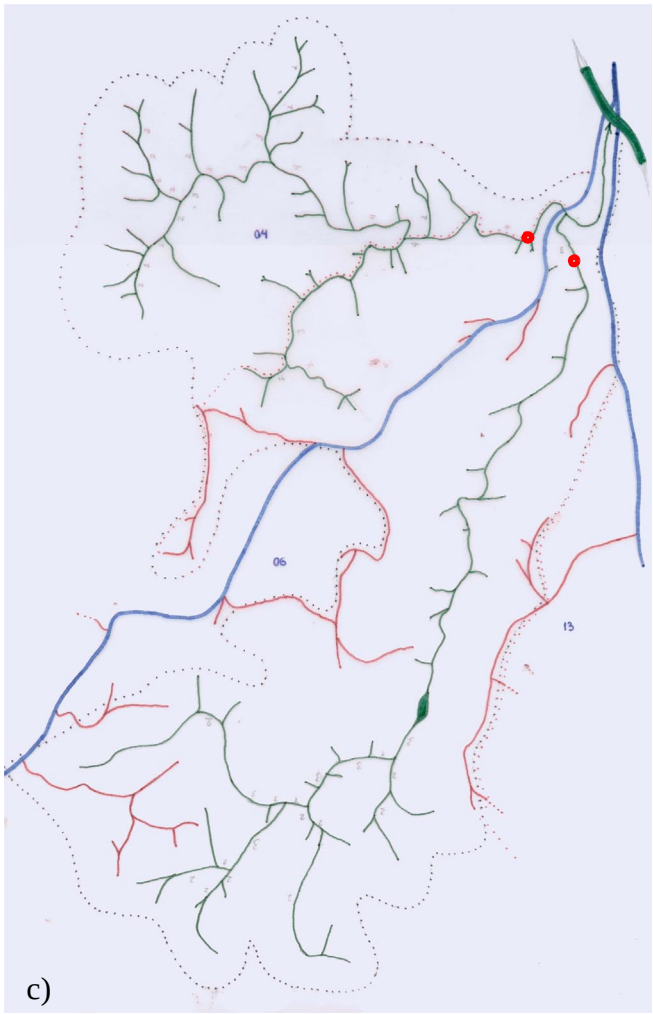
bance/recovery or ecotonal shift (Skole & Tucker, 1993; Tanner et al., 1998; Houghton et al., 2000; as cited by Weishampel et al., 2001). However, degradations, such as those resulting from selective logging have been undetected (Stone & Lefebvre, 1998; Nepstad et al., 1999) using commonly available satellite imagery and traditional methods of analysis.

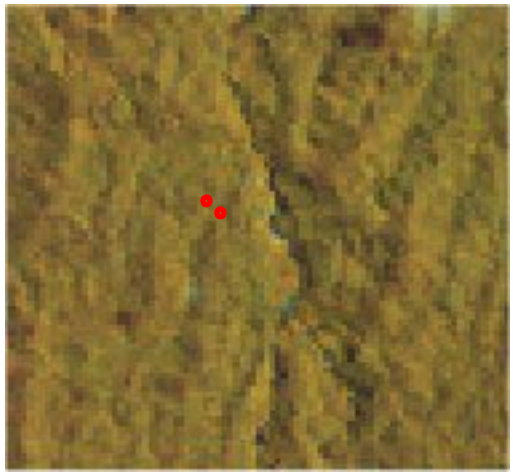
Vegetation classification, whether supervised or unsupervised, as well as NDVI index were not successful in distinguishing forest classes, from unlogged to logged forest of various logging intensities, and through the time. This confirmed results obtained by the Berau Forest Management Project who worked on vegetation mapping in East Kalimantan using Landsat TM (unpublished report). They could not use unsupervised and supervised classification. But, with visual interpretation including textural information besides spectral information, they discriminated eleven different forest classes, from primary forest to bare soils. Their results were based on one image and could not be applicable to another image with different raw data values (slightly different sun angle and shifted time acquisition would result in different image values).

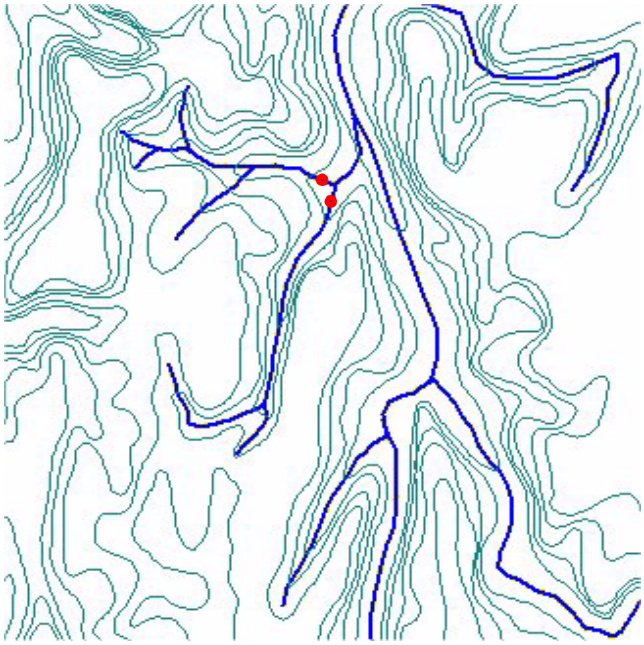
The NDVI index widely used for temperate vegetation, lost its sensitivity at high vegetation amount and have frequently been applied less successfully to tropical forests (Foody et al., 2000). Alternative approaches to NDVI which only uses two wavebands for biomass estimation, have been investigated by Foody et al. (2001). They found the neural network approach to be promising as it can use all wavebands acquired by the sensor.

As a consequence, vegetation classification could not be used to assess the effects of logging activities on the forest quality. However, measures of logging roads and skidtrails provided information on the intensity of logging activities on the spatial and temporal scales. Each scale used reflects different aspects of the study area, such as illustrated in figure 26. The satellite images placed the streams and the logging activities within a broader frame. With the five images at different time interval, the intensification of logging roads network within 10 years was put in evidence inside the Inhutani II timber concession. Outside the concession, the progressive «surrounding» of the study area, despite its remote access and the mountainous relief increasing the harvesting difficulties was also underlined. Map at 1:25’000 for contours and rivers (fig. 26 b) provided the first impression of the stream- and river network density, as well as the hilly relief and undulating plain. This was not observable at satellite imagery scale (fig 26 a). On field maps at scale 1:1’000, the interactions between the skidtrail network and the stream network emerged (fig. 26 c).

The relationships between the different scales have been addressed in hierarchy theory (Allen & Starr, 1982; O’Neil et al., 1986; both cited in Innes & Koch (1998), but many uncertainties remain, although the relationship between scale and the type of information required has been a central theme to the choice of remotely sensed data for some time (cf. Strahler et al., 1986; Woodcock & Strahler, 1987; both cited by Innes & Koch, 1998). The assessment of biodiversity need to include investigations at several different scales. Crossing these scale can be very difficult and pattern and scale represent a central problem in ecology (Levin, 1992). Issues of scale are also critical to the determination of ecosystem change. These relationships between scales could not be explored in this study due to insufficient data. The field maps could not be achieved for all sampling sites. Therefore, it was decided not to introduce these environmental variables at the stream catchment scale into the fauna and streams habitat analysis. As a result, the link and information transfer from the catchment scale to the stream reach scale and instream habitat was not possible.







a) 1991 Landsat image at scale 1:50’000
b) contour and river map at scale 1:25’000 with contour interval every 12.5 meters
c) field map at original scale 1:5’000, reproduced at approximately 1:10’000 with rivers in green, skidtrails in red

FIGURE 26. Same sampling sites at three different scales (1:50’000, 1:25’000 an 1:10’000). Red dots represent location of sampling site

In summary,

- satellite images are appropriate scale to assess logging activities by measuring logging roads network and its intensification accross the time, but effects of logging activities on the forest quality could not be assessed. Vegetation classification and NDVI index could not be used because of homogeneous forest cover.
- field maps at scale 1:1’000 were appropriate to assess logging intensity by the skidtrails network providing the proportion of the catchment which was logged, but were too time consuming to be effective in such a quickly-changing environment

CHAPTER 6

Environmental Variables and Macroinvertebrates

This chapter presents the results on ecological water quality defined by environmental variables and by macroinvertebrate community composition and functional organisation. Earlier (chapter two), it was discussed how streams and the macroinvertebrates inhabiting them are linked to each other, and how the catchment influenced the river system. This thesis examined these assumptions on the study area and the objective is:

> **To study the relationships between the stream habitat (environmental variables) and its fauna (benthic macroinvertebrate community), as indicator of ecological water quality in a tropical forest**

The chapter is divided into four parts: the first describes the environmental variables measured, the second describes the macroinvertebrate community composition which lead to a cluster analysis. In the third part, the relationships between environmental variables and macroinvertebrates are explored. In the fourth part, environmental variables and macroinvertebrates are then considered according to the obtained cluster groups.

6.1 Environmental variables

Environmental variables were explored with a normalised Principal Component Analysis (PCA). The two first axes (fig. 27c) explain 62.3% of the total variance. Environmental variables are represented in the correlation circle (fig. 27b) and their contribution to each axis F1, F2 and F3 are shown in table 13. Stream width and canopy opening contribute to axis F1, as well as depth and flow velocity: from larger streams on the right of axis F1 in fig. 27a) to smaller streams on the left of axis F1. Fine substrate, OM ratio and depth contribute to axis F2: samples with high composition of fine substrate, low Organic Matter ratio and shallow depth are located at the top of axe F2. Flow velocity and water temperature contribute to axis F3, which is not represented in fig. 27a).

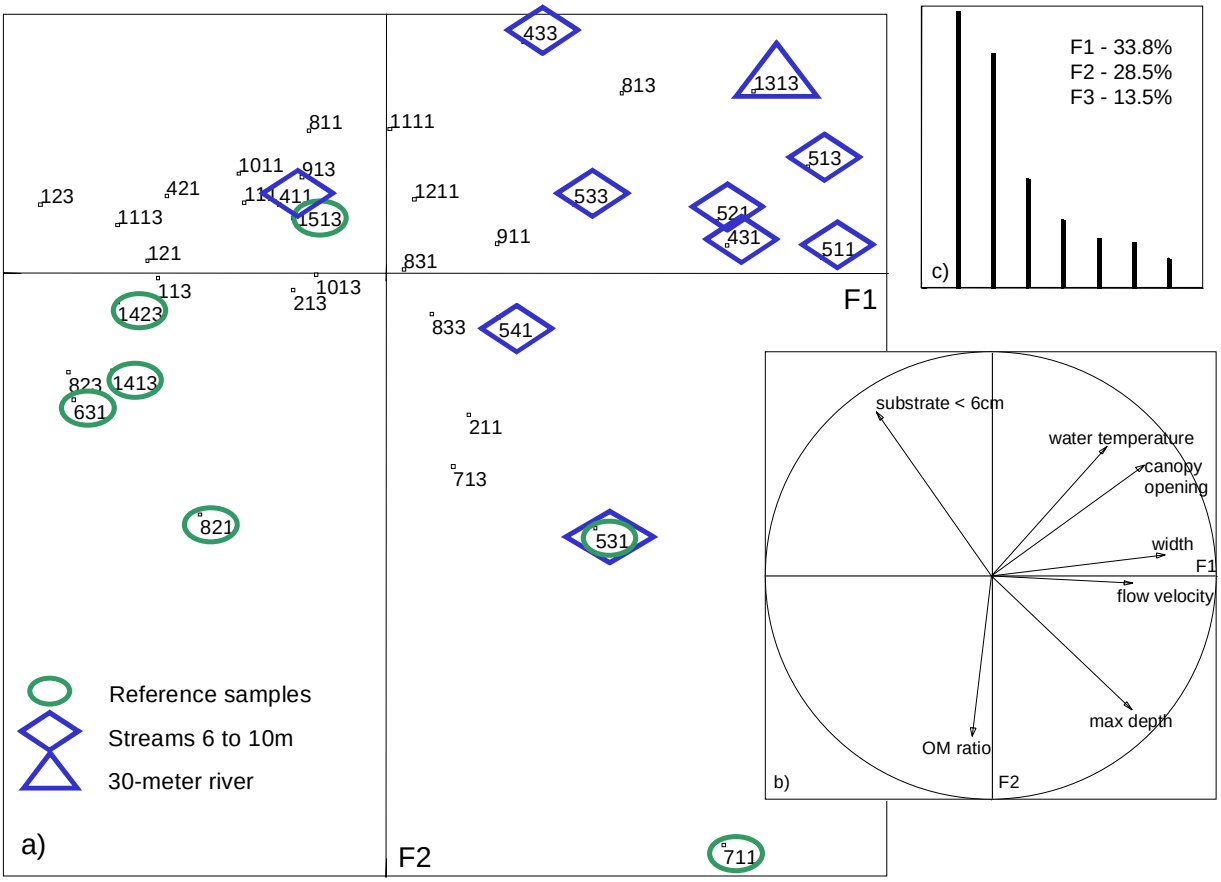


FIGURE 27. Principal Component Analysis (PCA) with environmental variables. a) represents the 36 samples. The ones without symbol belong to streams less than 6 meters. b) shows environmental variables and c) the eigenvalues expressed in percentage contribution.

TABLE 13. Contribution of each environmental variables to the factorial axes F1, F2 and F3.

Environmental variables	Contribution (%) to axis F1	Contribution (%) to axis F2	Contribution (%) to axis F3
Organic Matter ratio	0,3	25,8	17,0
Width	25,1	0,4	17,5
Depth	16,4	17,9	0,6
Flow velocity	16,7	0,1	41,1
Water temperature	11,1	16,7	19,9
Canopy opening	19,6	12,3	2,1
Fine substrate (< 6 cm)	10,8	26,9	1,7

Samples in the upper left quarter of fig. 27 a) are described by:

- higher percentage of fine substrate
- lower depth
- lower Organic Matter ratio

The upper right quarter of fig. 27a) contains mainly our larger streams (> 6 m) including our 30 m width-stream. They are described by:

- higher water temperature
- higher percentage canopy opening
- higher flow velocity
- higher depth

In the lower left quarter (fig. 27a), our reference sites are described by:

- lower water temperature
- lower canopy opening
- higher OM ratio

A between-class ordination was used to determine the relative contribution of the categorical environmental variables to the explanation of the dispersion of the samples in the PCA. Table 14 records between-class variance for each of the environmental variables. To test the statistical significance of this between-class variance, a 1000 random Monte-Carlo permutation test was used. Vegetation, logging activities and algae all exhibited significant between-class differences ($p<0.05$ in table 14). Each class of each categorical environmental variables represented by their between-class centre are illustrated in fig. 28.

Axis F1 and F2 are represented in fig. 28 for easiest comparison with fig. 27, but axis F3 is also discussed below.

Vegetation class 6 (primary unlogged forest) and class 2 (logged forest closed) are both on same bottom side of axis F2. **Logging activities** (fig. 28 b) are explained by axes F1 and F2: along axis F1 from right to left we observe the chronological logging sequence: 6 months - 1 to 3 years after logging - 4 to 5 years after logging. Axis F2 positive side gathers all logged samples whereas unlogged samples are located on the negative F2 side. **Algae** (fig. 28 c) are related to stream size along axis F1 with presence of algae in larger streams, but also to axis F2 with abundant algae on the top side.

Watershed, **sampling date** and **substratum colour** (fig. 28(d), (e) and (f)) have low discriminant power which indicates that these environmental variables do not explain much of the samples dispersion in the PCA. Rian and Seturan are considered as similar, as well as both sampling date and substratum. Despite the 8 months time interval, a seasonal effect is not perceptible with our environmental chosen variables.

TABLE 14. Variance from between-class ordination with each categorical environmental variable, tested with Monte-Carlo permutations test. Significance at p < 0.05.

Environmental variables	Class description	Between class variance (ratio)	Probability
Vegetation	(1) logged forest open - (2) logged forest closed - (3) pioneer vegetation - (4) secondary forest - (5) primary and secondary forest mixed - (6)primary forest	35.2%	p<0.01
Logging activities	Unlogged - during and 6 months after logging - 1 to 3 years after logging - 4 to 5 years after logging	19.8%	p=0.01
Algae	Absent - present - abundant	17.6%	p<0.01
Watershed	Rian - Seturan	6.2%	p=0.07
Sampling date	June-August 2000 - March-May 2001	4.4%	p=0.17
Substratum colour	dark - light - pale	5.5%	p=0.47

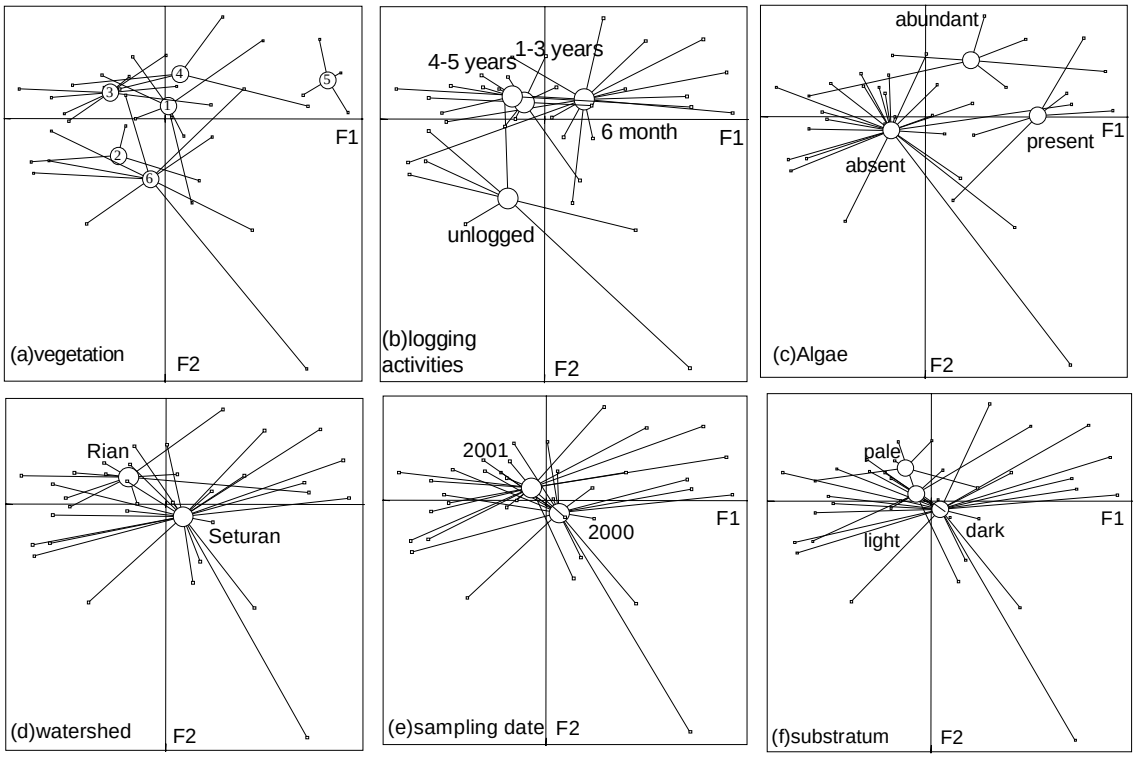


FIGURE 28. Star representation of discriminant centre for each category of each variable. For legend for upper left graph (a) on vegetation classes, see table 14, class description.

In summary, PCA illustrates that quantitative variables describing stream size contribute mostly to one axis (F1) which ordinate the samples from smaller streams to larger ones. Categorical variables (vegetation, logging activities and algae) contribute to explain quantitative variables with between class ordination.

Consequently to the results obtained with PCA, the 36 samples were grouped according to stream size (width) in order to compare them. Two classes were chosen: less than six meters width (n = 26 samples) and between six to ten meters width (n = 9 samples). One 30-meter width river was also sampled for comparison. Table 15 presents our environmental variables by mean average, standard deviation (Std. Dev.) and standard error (Std. Er.) for both group size. The 30 m width river single values appear in the last column as indicative values.

TABLE 15. Environmental variables with mean, standard deviation (Std. Dev.) and standard error (Std. Er.). * indicates that difference is significant with Mann-Whitney U-test with p<0.05 between the two stream size: <6 m and 6 to 10 m

Environmental variables	streams < 6m n=26			streams 6 to 10 m n=9			River 30m n=1
	Mean	Std.Dev.	Std. Er.	Mean	Std.Dev.	Std. Er.	
*Depth (m)	0.35	0.18	0.03	0.49	0.21	0.07	0.80
*Flow velocity (m/s)	0.58	0.21	0.04	0.96	0.26	0.08	0.65
*Water temperature (°C)	24.72	0.65	0.13	25.74	0.65	0.23	25.70
Air temperature (°C)	25.74	1.28	0.25	26.77	1.28	0.63	26.80
*Conductivity (µs/cm)	51.23	37.91	7.43	111.56	37.91	8.9	104.2
*Canopy opening (%)	14.24	11.55	2.26	29.56	11.79	3.92	86.3
Substrate composition (%):							
bedrock	9.00	20.23	3.9	1.22	3.31	1.1	0.00
boulder (>256 mm)	14.58	13.35	2.6	23.33	16.96	5.6	5.00
cobble (64-256 mm)	28.15	19.99	3.9	36.67	13.23	4.4	45.00
gravel (2-64 mm)	35.50	22.16	4.3	31.11	28.04	9.3	25.00
sand (0.06-2 mm)	10.08	10.66	2.1	4.89	6.13	2.0	25.00
siltclay (<0.06 mm)	2.69	8.03	1.6	3.33	8.03	1.4	0.00
substrate > 6 cm	51.73	23.89	4.7	61.22	25.78	8.6	50.00
substrate < 6 cm	48.27	23.89	4.7	39.33	23.89	8.5	50.00
Fine mineral Matter < 1 mm (gr)	27.45	18.17	3.56	27.77	18.6	6.2	33.37
Organic Matter FPOM (gr)	1.32	0.78	0.15	1.53	0.74	0.25	2.29
Organic Matter ratio (%)	6.97	5.03	0.98	6.35	2.25	0.75	6.87
Morphology types:							
small cascade (%)	3.69	7.93	1.5	0.00	0.00	0	0.00
riffle (%)	21.42	17.71	3.5	17.00	9.8	3.3	20.00
run (%)	53.96	27.14	5.3	53.33	23.05	7.7	50.00
pool (%)	20.92	24.65	4.8	28.56	26.90	8.9	30.00

The following five environmental variables were significantly different (Mann-Whitney U-test; p<0.05) between both stream sizes: depth, flow velocity, water temperature, conductivity, and canopy opening. The trend observed for each of these variables is:

- depth increases with river size
- flow velocity increases from smaller to larger streams
- water temperature increases by 1°C in larger streams. Air and water temperature are close to each other, with 1°C average difference only.
- conductivity is higher in larger streams
- canopy opening is higher in larger streams according to their width

TABLE 16. Significant differences (Mann-Whitney U-test; p<0.05) between June-August 2000 and March-May 2001 for some of the environmental variables with mean, standard deviation (Std. Dev) and standard error (Std. Er.). Streams < 6 m (n=13 in 2000; n=13 in 2001) and streams 6 to 10 m (n=6 in 2000; n=3 in 2001) were examined separately.

	June-August 2000			March-May 2001		
	Mean	Std. Dev.	Std. Er.	Mean	Std. Dev.	Std. Er.
Streams < 6 m:						
flow velocity (m/s)	0.66	0.19	0.05	0.49	0.2	0.05
conductivity (µs/cm)	67.42	33.13	9.19	35.04	36.4	10.12
run (%)	66.38	24.64	6.83	41.54	24.36	6.75
pool (%)	11.85	21.41	5.9	30	25.1	6.95
Streams 6 to 10 m:						
conductivity (µs/cm)	99.48	19.25	7.86	134.5	26.78	15.46

In table 16, for streams < 6 m width, flow velocity, conductivity, proportion of pool and run were significantly different between June-August 2000 and March-May 2001 (Mann-Whitney U-test; p<0.05). Conductivity was significantly different in streams 6 to 10 m width (Mann-Whitney U-test; p<0.05).

In summary, stream size is highlighted as an important variable to take into account in this study. Depth, flow velocity, water temperature, conductivity and canopy opening are significantly influenced by stream size and their values increase with it. But stream size does not explain variation in any of the other variables (air temperature, substrate composition, fine mineral matter, Fine Particulate Organic Matter and morphology type).

6.2 Macroinvertebrate fauna

6.2.1 List of macroinvertebrate taxa collected during the study

The total number of macroinvertebrates individuals collected during June-August 2000 and March-May 2001was approximately 15’000 individuals, distributed among 115 taxa. Qualitative and quantitative date were used to establish table 17, which lists the aquatic fauna encountered, by order, family, sub-family/ genera, with their belonging to functional feeding groups, mainly following Dudgeon (1999), John Morse (pers. com.) and Tachet et al. (2000).

Of the 43 Ephemeroptera genera identified, 12 are undescribed: 6 Baetidae genera, 2 Caenidae, 1 Ephemerellidae, 1 Heptageniidae, 1 Leptophlebiidae and 1 Teloganodidae.

Three Ephemeroptera genera were the most abundant and widespread macroinvertebrates collected: *Cinygmina* (Heptageniidae) represents 11.7% of all macroinvertebrates collected and was encountered in 35 of 36 samples, *Platybaetis* (Baetidae) represents 8.4% and was encountered in 15 samples and *Euthraulus* (Leptophlebiidae) widespread as well, represents 6.7% and was encountered in 34 samples.

TABLE 17. List of macroinvertebrate taxa with level of identification and functional feeding groups. * for undescribed taxa. Feeding groups: P=predator; Sh=shredder; Sc=scraper; Co=collector; CoSc=collector-scraper; CoSh=collector-shredder;F=filtrer.

Order	Family	Sub-family/genera	Feeding groups
Coleoptera	Dytiscidae		P
	Elmidae		CoSc
	Eulichadidae		CoSh
	Georissidae		?
	Gyrinidae		P
	Hydrophilidae		CoSc
	Lampyridae		?
	Psephenidae		Sc
	Scirtidae		Co
Diptera	Athericidae		P
	Empididae		P
	Stratiomyidae		Sc
	Ceratopogonidae		P
	Chironomidae		Co
	Limonidae (Tipulidae)		Sh/P
	Psychodidae		Co
	Rhagionidae		P
	Simuliidae		F
Ephemeroptera	Baetidae	Alainites	CoSc
		Cloeodes	CoSc
		*Genus 2	CoSc
		*Genus 4	CoSc
		*Genus 5	CoSc
		*Genus 6	CoSc
		*Genus 7	CoSc
		Jubabaetis	CoSc
		Labiobaetis	CoSc
		Liebebiella	CoSc
		Platybaetis	CoSc
		“Platybaetis” probus	CoSc
		Pseudocentroptiloides	CoSc
		*Genus 3	CoSc
	Caenidae	Brachycercus	CoSc
		Caenis	CoSc
		Caenodes	CoSc
		Clypeocaenis	CoSc
		*Genus 8	CoSc
		*Genus 9	CoSc
	Ephemerellidae	Hyrtanella	CoSh
		*Genus 1	CoSh
		Uracanthella	CoSh
	Heptageniidae	*Genus 10	CoSc
		Asionurus	CoSc
		Atopopus	CoSc

TABLE 17. (Continued) List of macroinvertebrate taxa with level of identification and functional feeding groups. * for undescribed taxa. Feeding groups: P=predator; Sh=shredder; Sc=scraper; Co=collector; CoSc=collector-scraper; CoSh=collector-shredder;F=filtrer.

Order	Family	Sub-family/genera	Feeding groups
		Cinygmina	CoSc
		Nothacanthurus	CoSc
	Leptophlebiidae	Choroterpes	CoSc
		Dipterophlebiodes	CoSc
		Euthraulus	CoSc
		Habrophlebiodes	CoSc
		Isca	CoSc
		*Genus 11	CoSc
	Neoephemeridae	Potamanthellus	F
	Isonychiidae	Isonychia	F
	Euthyplociidae	Polyplocia	F
	Potamanthidae	Rhoenanthus	F
		Potamanthus	F
	Prosopistomatidae	Prosopistoma	Sc
	Teloganodidae	*Genus 12	CoSc
		Teloganodes	CoSc
	Teloganellidae	Teloganella	CoSc
Heteroptera	Aphelocheridae		P
	Gerridae		P
	Helotrephidae		P
	Naucoridae		P
	Nepidae	Ranatrinae	P
	Veliidae		P
Lepidoptera	Pyralidae		Sc
Megaloptera	Corydalidae		P
Odonata	Aeschnidae		P
	Gomphidae		P
	Libellulidae		P
	Macromiidae		P
	Amphipterygidae		P
	Calopterygidae		P
	Euphaeidae		P
	Lestidae		P
	Platystictidae		P
Plecoptera	Leuctridae		Sh
	Nemouridae		CoSh
	Peltoperlidae		Sh
	Perlidae		P
Trichoptera	Calamoceratidae		ShSc
	Ecnomidae		P
	Glossossomatidae		Sc
	Helicopsychidae		Sc
	Hydropschidae	Diplectroninae	F
		Hydropsychinae	F
		Hydropsychinae 1	F
		Hydropsychinae 2	F

TABLE 17. (Continued) List of macroinvertebrate taxa with level of identification and functional feeding groups. * for undescribed taxa. Feeding groups: P=predator; Sh=shredder; Sc=scraper; Co=collector; CoSc=collector-scraper; CoSh=collector-shredder;F=filtrer.

Order	Family	Sub-family/genera	Feeding groups
		Hydropsychinae 3	F
		Hydropsychinae 4	F
		Hydropsychinae 5	F
		Hydropsychinae 7	F
		Macronematidae	F
	Hydroptilidae		Sc
	Leptoceridae		CoSc
	Philopotamidae		F
	Polycentropodidae	Polycentropodinae	P
		Pseudoneureclipsinae	P
	Psychomyidae		Co
	Xyphocentronidae		Co
Achete			P
Decapoda	Brachyura		P
	Palaemonidae	Macrobrachium	Sh
Gastropoda	Thiaridae		ShSc
Gordiaceae			Parasite
Hydrachnide			P
Isopoda			?
Oligochete			Deposit-feeders
Tricladida	Dugesiidae		P?

On the other hand, eleven taxa were collected in few specimen and were present in one location only: Aeschnidae and Macromiidae (Anisoptera), Psychodidae and Rhagionidae (Diptera), Baetidae Genus 6, *Brachycercus* (Caenidae), *Asionurus* and *Nothacanthurus* (Heptageniidae), *Dipterophlebiodes* (Leptophlebiidae), Nemouridae (Plecoptera), Lestidae (Zygoptera).

Ephemeroptera could be identified to generic level, due to available information as well as the expertise from the Museum of Zoology in Lausanne, Switzerland. From literature (Sartori et al., in press), table 18 compares the number of Ephemeroptera genera and species collected and identified since 1881 in the whole Borneo island with the data (estimated number of species) collected in the study area covering 80 km^2. In total more than 40 mayfly genera and probably more than 50 species have been identified from the study area. This represents broadly the same diversity as it was previously known for the whole island.

Despite the fact that the total number of genera and estimated species are higher in the study area, four families are recorded in the literature without having been collected in our study. These are the Ephemeridae (*Eatonigenia*), Palingeniidae (*Anagenesia*), Polymitarcyidae (*Ephoron*, *Povilla*) and Tricorythidae (*Tricorythus*). Palingeniidae, Polymitarcyidae and Ephemeridae are burrowing mayflies and probably do not occur in the stony headwater streams we investigated. The following information is based on (Sartori et al., (in press)).

Baetidae is the most diversified family since 12 genera have been recognised. Most abundant are *Labiobaetis*, *Platybaetis* and *Jubabaetis*. Noteworthy is also the presence of *Cloeodes* and *Liebebiella*. The genera *Alainites*, *Jubabaetis* and *Pseudocentroptiloides* are recorded for the first time in Borneo. 5 new taxa could not be identified and have to be described.

TABLE 18. Number of Ephemeroptera genera and species collected in Borneo region according to literature references, compared with the one collected in the present study.

Family	Literature		Present study	
	Genera	Species	Genera	Species
Baetidae	7	9	14	>13
Caenidae	1	1	6	>6
Ephemerellidae	2	2	3	3
Ephemeridae	1	1	0	0
Euthyplociidae	1	2	1	1
Heptageniidae	6	7	5	7
Isonychiidae	1	1	1	1
Leptophlebiidae	7	7	6	>7
Neoephemeridae	1	1	1	1
Palingeniidae	1	5	0	0
Polymitarcyidae	2	3	0	0
Potamanthidae	2	2	2	2
Prosopistomatidae	0	0	1	1
Teloganellidae	1	1	1	1
Teloganodidae	1	1	2	2
Tricorythidae	1	1	0	0
Total number	**35**	**44**	**43**	**>45**

Heptageniidae. The most common and diversified genus has been identified as *Cinygmina*. At least 3 different species have been found. *Atopopus* nymphs are also relatively abundant in the investigated area; based on the capture of male imagoes, they have been identified as *Atopopus* tarsalis Eaton, 1881. Only the nymph of *A. edmundsi* (Wang & McCafferty, 1995) was previously known. Three other taxa were not identified with certainty and are related to *Asionurus*, *Trichogenia* or even *Notacanthurus*.

Leptophlebiidae. *Euthraulus* is among the most common genus among the identified Ephemeroptera. Other Leptophlebiidae are less abundant, although *Isca* and *Habrophlebiodes* (both recorded for the first time from Borneo) are not rare. *Dipterophlebiodes* and *Thraulus* have been found in a few localities, whereas an unknown genus could perhaps represent the nymphs of *Simothraulus* and/or *Sulu* that are only known at the adult stage.

Isonychiidae. Some nymphs of *Isonychia* have been collected that could represent the unknown immature stage of *I. winkleri* Ulmer, 1939, the only species so far known from Borneo. Identification in the laboratory in order to establish the correspondence with adults caught by light traps will probably bring soon an answer.

Potamanthidae. Two species have been found, belonging to the genera *Rhoenanthus* and *Potamanthus* (subgenus *Stygifloris* endemic to Borneo). But at the moment, we are not convinced our specimens are conspecific with the two potamanthid mayflies known from Borneo: *Potamanthus* (*Stygifloris*) sabahensis Bae, McCafferty & Edmunds, 1990 and *Rhoenanthus* speciosus Eaton, 1881.

Euthyplociidae. Several nymphs belonging to the genus Polyplocia have been collected. Here again, specific attribution will need further studies. Two species have been described by Ulmer at the adult stage (P. *campylociella* Ulmer, 1939 and *P. crassinervis* Ulmer, 1939) but only one is known at the larval stage (Demoulin, 1966), and its specific attribution is uncertain.

Ephemerellidae. Two genera have been found that match the descriptions of *Uracanthella* and *Hyrtanella*. This later is most likely endemic to Borneo. The nymphs we collected are very different from those of the single species known, *H. christinae* Allen & Edmunds, 1976. *Uracanthella* is probably represented by two species.

Teloganodidae. The genus *Teloganodes* was quite common in the area, as is another and yet undescribed genus. The concept of *Teloganodes* needs a careful revision. Described from Sri Lanka on female subimagoes, *Teloganodes tristis* Hagen, 1858 has been subsequently reported from Borneo by Ulmer (1939) as nymphs and later on in other countries from South East Asia (Hubbard & Pescador, 1978; Hubbard & Peters, 1984; Soldán, 1991; Tong & Dudgeon, 2000). It still has to be confirmed if the population from Sri Lanka and from Borneo belong to the same species, or even to the same genus.

Teloganellidae. This family has been defined recently for the monotypic *Teloganella umbrata* Ulmer, 1939 (McCafferty & Wang, 2000). We collected very few males with light traps and a single nymph of this species. Anyway, all stages need to be correctly redescribed before any phylogenetic relationship or family assessment could be completed.

Neoephemeridae. The few nymphs that were caught fit the description of the single species known from Borneo and described by Ulmer as *Neoephemeropsis caenoides* (Ulmer, 1939). This genus has been recently put in synonymy with *Potamanthellus* (Bae & McCafferty, 1998). *Potamanthellus caenoides* has also been recorded from continental Asia.

Caenidae. The study of this family has brought a lot of surprises. Only *Caenis* and/or *Caenodes* were previously known. They are the most abundant in our samples. Besides, we collected *Clypeocaenis* nymphs (first record for Borneo), as well as what seems to be *Brachycercus*. If the latter identification is correct, it would extend the known distribution of this holarctic genus far to the East since the only Oriental species is known from Sri Lanka. Two different taxa could not be assigned to anything and probably represent new genera. With at least 5 genera, the Caenidae is surprisingly one of the most diversified family in Borneo.

Prosopistomatidae. This monogeneric family is recorded for the first time in Borneo. The species of *Prosopistoma* we collected is very rare and has only been found in the most remote places with intact primary forest. Our first analyses show it to belong to a new species sharing more affinities with some continental species than with *P. wouterae* Lieftinck, 1932 from Java and Sumatra.

In summary, stream benthic macroinvertebrate richness, with more than 115 taxa identified on a area covering less than 10x10 km, is among the highest found in the world. Particularly considering the 43 mayfly genera, including 12 unidentified genera which are probably new for science. This high number of unidentified genera within the Ephemeroptera let guess that many other unidentified genera will be discovered within the other orders; this underlining how little is known from this area.

6.2.2 Macroinvertebrate composition (first part)

In order to explore the interrelationships between samples and taxa, a Correspondence Analysis (CoA) was used to obtain a "corresponding" sample and taxa ordination.

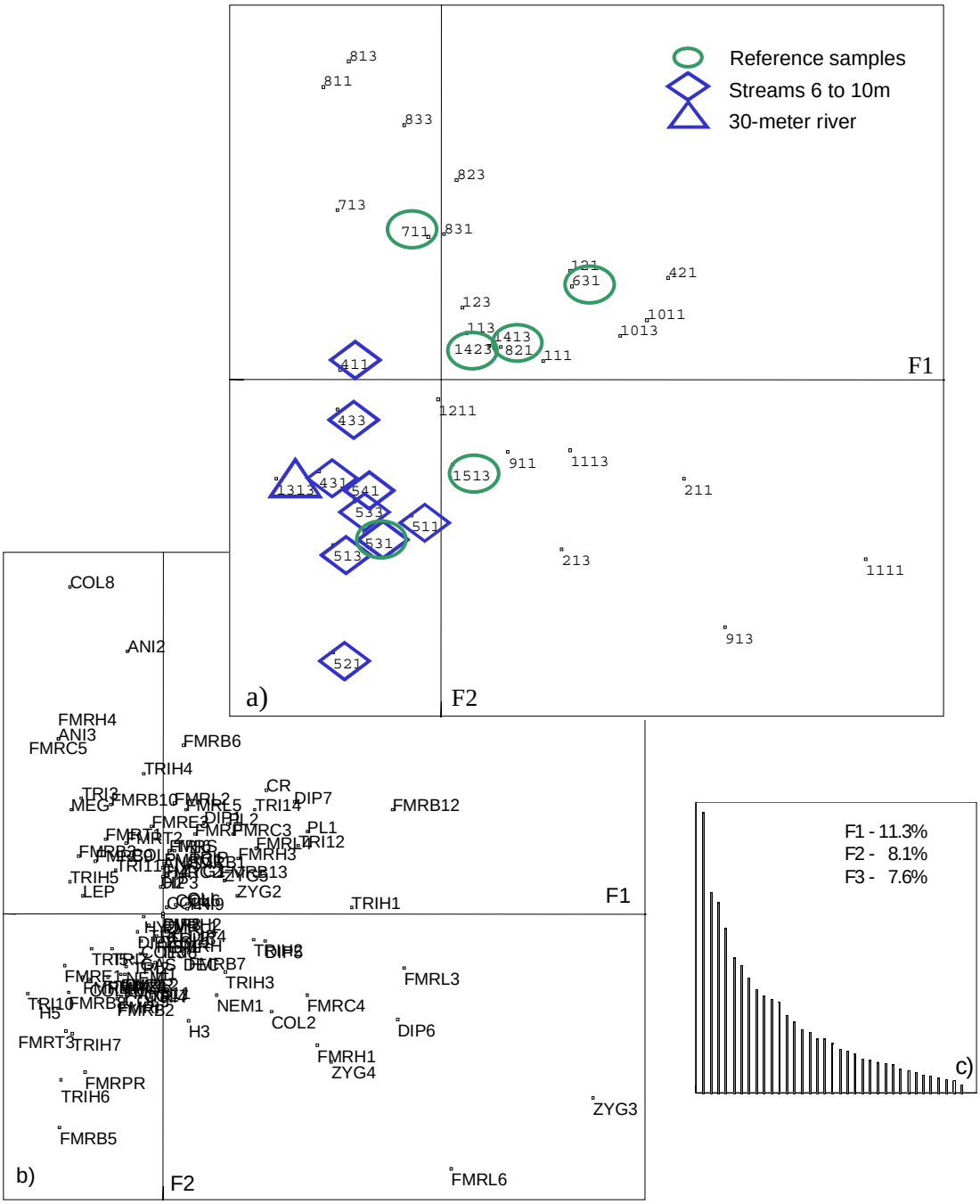


FIGURE 29. Correspondence Analysis with macroinvertebrate abundance. a) representation of the 36 samples. The ones without symbol all belongs to streams less than 6 meter width. b) taxa representation by code and c) eigenvalues

The three first axes, F1, F2 and F3 only explained 27% of the total variance (fig. 29c). This low value underlines the complexity of macroinvertebrate composition: samples are composed by an assemblage of numerous taxa, with no real dominant ones. All samples on streams larger than 6 meters width are found on the left down quarter on the figure 29a).

Figure 29b) illustrates the taxa and it is fairly difficult, at this point, to explain or understand the samples "position" along axes with faunistical composition. Therefore, the data exploration will be further continued with a classification analysis. The importance of stream size underlined with environmental variables analysis was taken into account. Until the end of this chapter, all figures and tables reports: streams < 6 m, streams 6 to 10 m, and the particular sample on the 30-meter width river.

6.2.3 Macroinvertebrate density and richness

From the qualitative data set, 115 taxa were obtained in total, the maximum number of taxa in one sampling site was 64 and the minimum was 12. 9 taxa were found only in qualitative samples: Aeschnidae (Anisoptera); Rhagionidae (Diptera); *genus* 6 (Baetidae - Ephemeroptera); *Asionurus* (Heptageniidae - Ephemeroptera); *Dipterophlebiodes* (Leptophlebiidae - Ephemeroptera); Ranatrinae (Heteroptera), Nemouridae (Plecoptera), Isopoda and Acheta. No statistical analysis were performed on the qualitative data.

For the quantitative data set, the abundance of each of the 106 taxa in each Surber was recorded and recalculated per square meter. The mean number of individuals (m^{-2}) calculated on the 36 samples is: 771 (Std. Dev. = 455; Std. Er. = 76), ranging from 86 to 2'130 individuals (m^{-2}). Densities for each sample are presented in Appendix II.

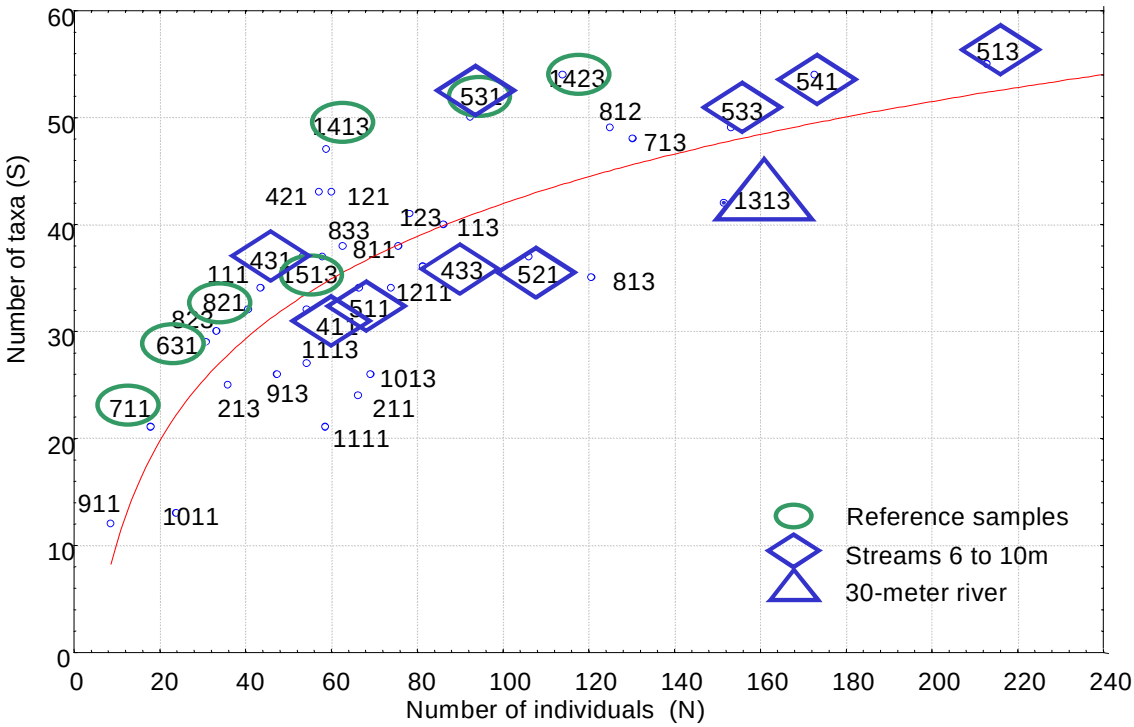


FIGURE 30. Number of individuals (N) and number of taxa (S) with fitting curve in red. All 36 samples are represented. The ones without symbol are all streams less than 6 meters width.

In fig. 30 the number of taxa (S) and the number of individual (N) for each sample was plot. All reference samples (green circle) are above the fitting log curve and larger streams (blue diamonds and triangle) are located on the slowly raising part of the curve. As more individuals have been collected (sampling effort), more taxa are recorded. The sampling curve rises rapidly at first, then slowly until an asymptote is almost reached. Such differences in abundance will make it difficult to compare diversity between samples without data transformation.

In order to be able to compare samples, Ecosim software rarefaction module (Gotelli et al, 2001) was used to "reduce" the number of taxa to the lowest number of individuals. This rarefaction methods recalculated a mean number of taxa for each sample.

TABLE 19. Mean number of individuals (N), mean number of taxa observed and mean number of taxa after rarefaction, per stream sizes < 6 m and 6 to 10 m, together with value from 30 m river width. * show significant difference with Mann-Whitney U-test.

	stream < 6 m n= 26			streams 6 to 10 m n=9			30m river
	Mean value	Std.Dev.	Std. Er.	Mean value	Std Dev.	Std. Er.	n=1
*No. of individuals (N)	628	322	63	1104	567	189	1517
*No. of taxa (S)	33.3	10.8	2.1	42.6	9.2	3.1	42
No. of taxa after rarefaction	29.3	8.1	1.6	34.2	3.9	1.3	33.2

Table 19 presents by stream size, the mean number of individuals (N), the mean number of taxa collected (S) and the mean number of taxa after rarefaction. Difference between both stream size is significant with Mann-Whitney U-test for density (p=0.019) and for number of taxa (p=0.039). Mean number of individuals and taxa are higher in larger streams. After rarefaction, the number of taxa is not any more significantly different between streams size with Mann-Whitney U-test (p=0.09). This underlines the effect of the number of individuals collected on the number of taxa (sampling effort).

In summary, density of macroinvertebrates is significantly higher in larger streams compared to smaller streams, but richness (after correction for sampling size effect) is not significantly different between streams of different size.

6.2.4 Macroinvertebrate Alpha Diversity

Table 20 presents richness and diversity indices according to stream size, based on results obtained with environmental variables. Some of the indices that were calculated are presented; the most relevant ones and widely used (such as Shannon index) to allow comparisons. Shannon H' maximum is the only index to be significantly different with Mann-Whitney U-test (p=0.04). The following trends can be observed:

- α LOG SERIES, another richness index, is similar between both stream size <6m and 6 to 10m, but has a lower value in the 30 m river width.
- SHANNON INDEX H', AND H' MAXIMUM. Both H' and H' maximum are high in average and are relatively close to each other, meaning that some of the samples are very close to the maximum H' possible. Shannon H' and H' maximum tends to be higher in streams 6 to 10 m compared to streams < 6 m.
- Evenness, with both PIELOU J AND MODIFIED HILL'S RATIO are quite similar between stream size, but both tend to be lower in larger streams. Pielou J, ranges from 0.53 to 0.92, on a scale from 0 to

1. These high values indicate that some samples approaches the evenness (i.e. same number of individuals per species). Modified Hill's ratio, ranges from 1.36 to 23.62. This index approaches 0 as a single species becomes more and more dominant. The mean average is quite high.

- Dominance values with BERGER-PARKER index are in accordance with evenness indices. Dominance values are low in both stream size and quite similar, but tend to increase with stream size. It measures the fraction of the dominant taxa.

TABLE 20. Mean richness and diversity indices compiled by stream size. * significant difference with Mann-Whitney U-test (p<0.05).

Diversity Indices	streams < 6m n=26			streams 6 to 10 m n=9			30m river
	Mean value	Std.Dev.	Std. Er.	Mean value	Std Dev.	Std.Er.	n=1
Richness: Alpha Log Series	11.93	3.87	0.76	12.20	1.78	0.59	10.94
Heterogeneity: Shannon H'	2.77	0.49	0.09	2.85	0.35	0.12	2.75
*Shannon H' maximum	3.44	0.37	0.07	3.73	0.21	0.07	3.73
Evenness: Pielou J index	0.80	0.08	0.02	0.76	0.07	0.02	0.74
Evenness: Modified Hill's ratio	10.7	5.69	1.1	9.17	4.49	1.49	7.01
Dominance: Berger-Parker	0.23	0.13	0.02	0.27	0.1	0.03	0.30

In summary:

- richness and diversity indices do not exhibit any significant difference between streams of different size, except for Shannon H' maximum (LnS), which is significantly higher in larger streams

6.2.5 Ephemeroptera, Plecoptera and Trichoptera composition

The three orders, Ephemeroptera, Plecoptera and Trichoptera (EPT) are often used as an index in bioassessment studies (e.g. Barbour et al., 1995; Plafkin et al., 1989). Each group by itself or in their total proportion (EPT%) compared to all others groups. Despite the low abundance of Plecoptera in the samples, these EPT are presented below in order to be comparable with other studies.

Figure 31a), illustrates the different proportion for each order Ephemeroptera, Plecoptera, Trichoptera and the "others", which encompassed the Diptera, Coleoptera, Heteroptera, Odonata and all others taxa encountered in the study; among them, the Diptera and Coleoptera dominated. **Ephemeroptera** highly dominate in proportion in all stream size and tend to increase with stream size. **Trichoptera** and all the "**others**" are well represented with ~20% in both stream size (<6m and >6m). Trichoptera proportion in the 30 m river is low with 8%. **Plecoptera** are in low proportion in all stream size.

The proportion EPT is high in all stream size: 69% in streams < 6m, and higher in streams 6 to 10m (81%) and in the 30m width river (79%).

Figure 31b), illustrates the number of individuals in each order. Density of Ephemeroptera remains dominant in all stream size and increases with it. Significant differences with Mann-Whitney U-test appear between streams < 6m and streams > 6m for Ephemeroptera (p=0.009) and Plecoptera (p=0.005).

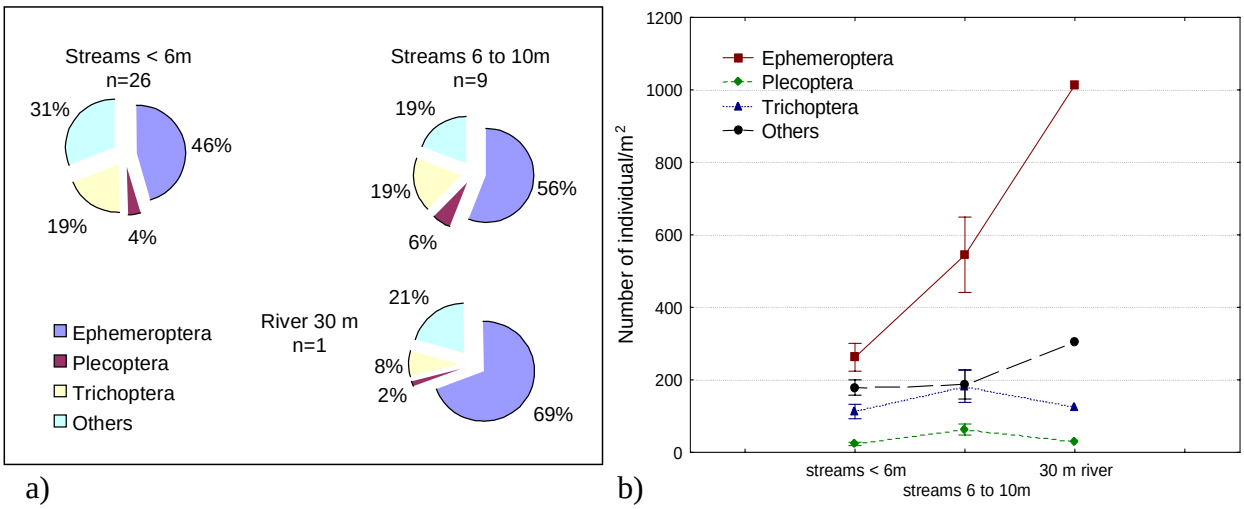


FIGURE 31. **Ephemeroptera, Plecoptera, Trichoptera and other orders are expressed in percentages from the average number of individuals by stream size, on graph a). On graph b), they are expressed in mean number of individuals per square meter, with standard error bar.**

In summary:

- %EPT is high in average (around 75%) compared to temperate climate and higher in larger streams compared to smaller ones
- Ephemeroptera are dominant in proportion and density whatever the size of the stream is

6.2.6 Macroinvertebrate functional feeding groups

Taxa with unknown functional feeding behaviour are left apart. Taxa belonging to more than one feeding group are summed up under omnivorous category. This category includes: true omnivorous, filtrer-predator, shredder-predator and shredder-scrapper. Figure 32 illustrates the different proportion of each functional feeding group ordered by stream size.

The proportion of **predators** slightly increases with streams larger than 6 m, but is low in the 30 m river width (as we only have one 30 m river, this trend cannot be confirmed). The proportion of **grazers-scrapers** increases in streams > 6 m. River 30 m width has a high proportion as well. **Omnivorous** proportion decreases regularly from the smaller streams (18%) to larger ones (15% and 13%).

The **detritivorous** proportion as a whole (shredder + filtrer + collector): 35% in streams < 6m, 21% in streams > 6m decrease with stream size, but is high in the 30m river (33%).

- the **shredders** proportion is low and increases with stream size. River 30 m width homes 143 individuals per square meter, representing 10%.
- **filtrers** proportion is low and decrease (12% - 6% - 2%) with increasing stream size.

- **Collectors** decrease in proportion from streams < 6 m to streams 6 to 10 m, but proportion in 30m river is similar than in smaller streams (< 6m).

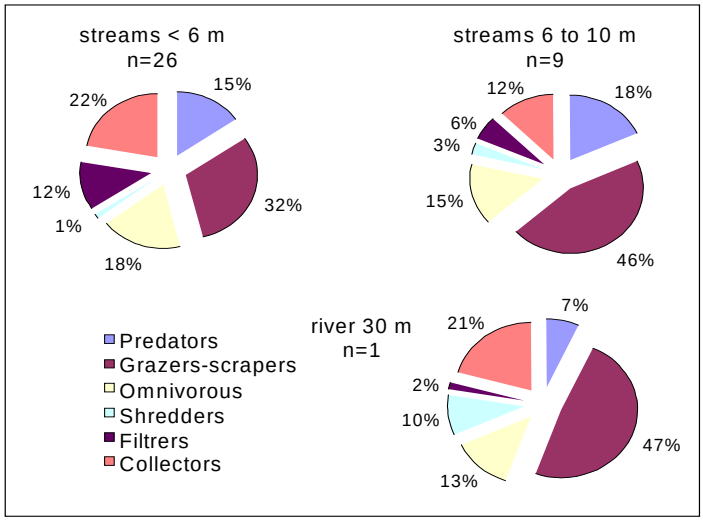


FIGURE 32. Functional feeding groups expressed in percentage of the number of individuals by stream size. Shredders, Filtrers and Collectors are detritivorous (using allochtonous organic matters).

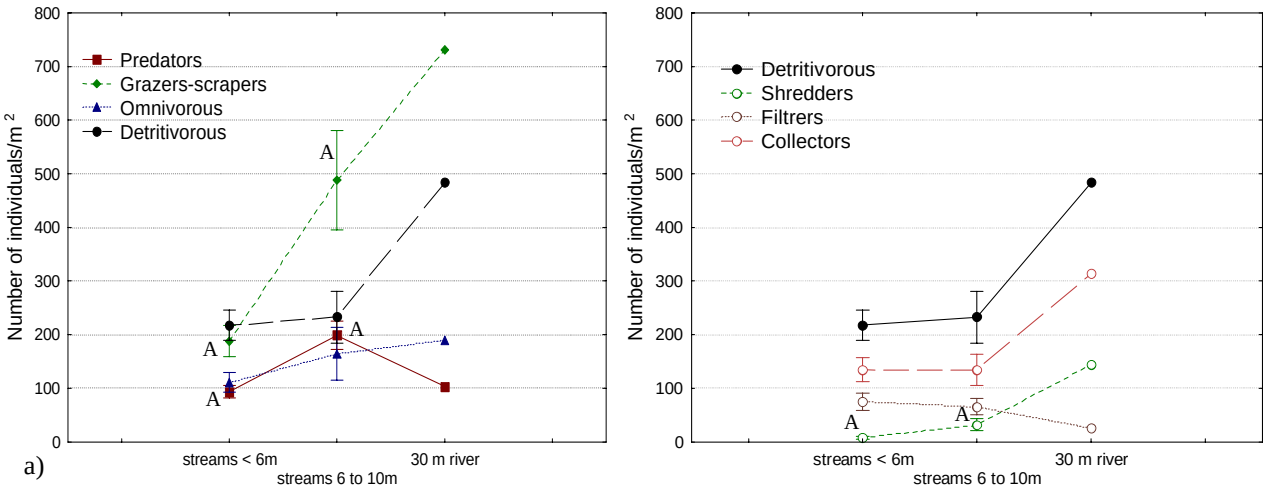


FIGURE 33. Mean density of individual for each functional feeding groups are presented by stream size: streams < 6m (n=26), streams 6 to 10m (n=9) and 30m river (n=1). Graph a) represents predators, grazers-scrapers, omnivorous and detritivorous; graph b) details detritivorous in shredders, filters and collectors. Same capital letter indicates significant difference between groups with Mann-Whitney U-test (p>0.05).

Figure 33 illustrates the density of the functional feeding groups. There are significant differences between streams < 6m and streams 6 to 10m for predators (p=0.0009), grazers-scrapers (p=0.002) and shredders (p=0.016) with Mann-Whitney U-test.

The number of **predator** is higher in streams 6 to 10m compared to streams < 6m, which could follow the general increase in all other groups (i.e. more preys available), but is low in the 30-meter river.

The number of **detritivorous** as a whole, is dominant in streams < 6m, with **grazers-scrapers** in second position in numbers, these reflecting the higher allochtonous input in smaller streams. In larger streams > 6m, the situation is reverse, with highly dominant number of grazers-scrapers, but same number of detritivorous than previously, this in turn reflects the higher autochtonous source.

The proportion of feeding group relying on allochtonous source (detritivorous) tends to decrease with increasing stream size (35% in streams < 6m, 21% in streams 6 to 10m and 33% in the 30 m river). The proportion of feeding group relying on autochtonous source (grazers-scrapers) tends to increase with increasing stream size (32% in streams < 6m, 46% in streams 6 to 10m and 47% in the 30m river.

In summary,

- predators, grazers-scrapers and shredder are significantly higher in larger streams
- shredders are in very low proportion and density but increase with stream size;
- filtrers tend to decrease with stream size;

6.2.7 Macroinvertebrate composition (second part)

The cluster analysis was used to group samples in order to test whether samples cluster randomly or according to an underlining structure. Factorial scores of the samples and the three first axes obtained with the CoA were used to perform the cluster analysis. Euclidean distance and Ward method gave the cluster illustrated in figure 34. Euclidean distance, an index of dissimilarity that is sensitive to changes in abundance, has been shown to be responsive to differences in macroinvertebrate communities in disturbed versus undisturbed watersheds, whereas indices that utilise proportional abundance vary less in response to disturbance (Newbold et al., 1980). Samples are distributed in the cluster groups following their faunistical composition similarity.

In the first step, **Group 1** is separated from the three others. It will be referred to as **group red**, including **the most disturbed samples**. As a matter of fact, all samples of this group, except 421 were located in area logged in 1998-1999 (1 to 3 years after logging). 421 belonged to an area logged in 1995 (5 years after logging), but was described as “heavily disturbed”: surrounding forest was clear cut to create a landing area (area where logs were stored before being loaded on trucks for transportation outside the concession).

In the second step, Group 3 and 4 remained together when Group 2 split. **Group 2 in green** includes the highest number of samples, which all belong to stream size < 6 m (such as Group 1). Within this group, the following samples can be found:

- 5 reference samples: 631, 1513, 1423, 1413 and 821
- 2 sites 4 years after logging: 121 and 111, resampled the following year when they were on relogging activities: 123 and 113
- 823 was just finished to be logged, but the surrounding forest at the sampling sites was relatively lightly impaired
- 2 sites 2 years after logging: 1211 and 911

This group 2 will be referred to as **group green** with the **highest number of reference samples**.

Group 3 gathered all our streams > 6 m width. This group contains mainly the sampling sites during logging and 6 months after logging, but as well one reference sample (531) and 2 samples 5 years after logging (431 and 411) with one replicate that was on relogging activities (433). This group will be referred to as **group blue** containing **all larger streams**.

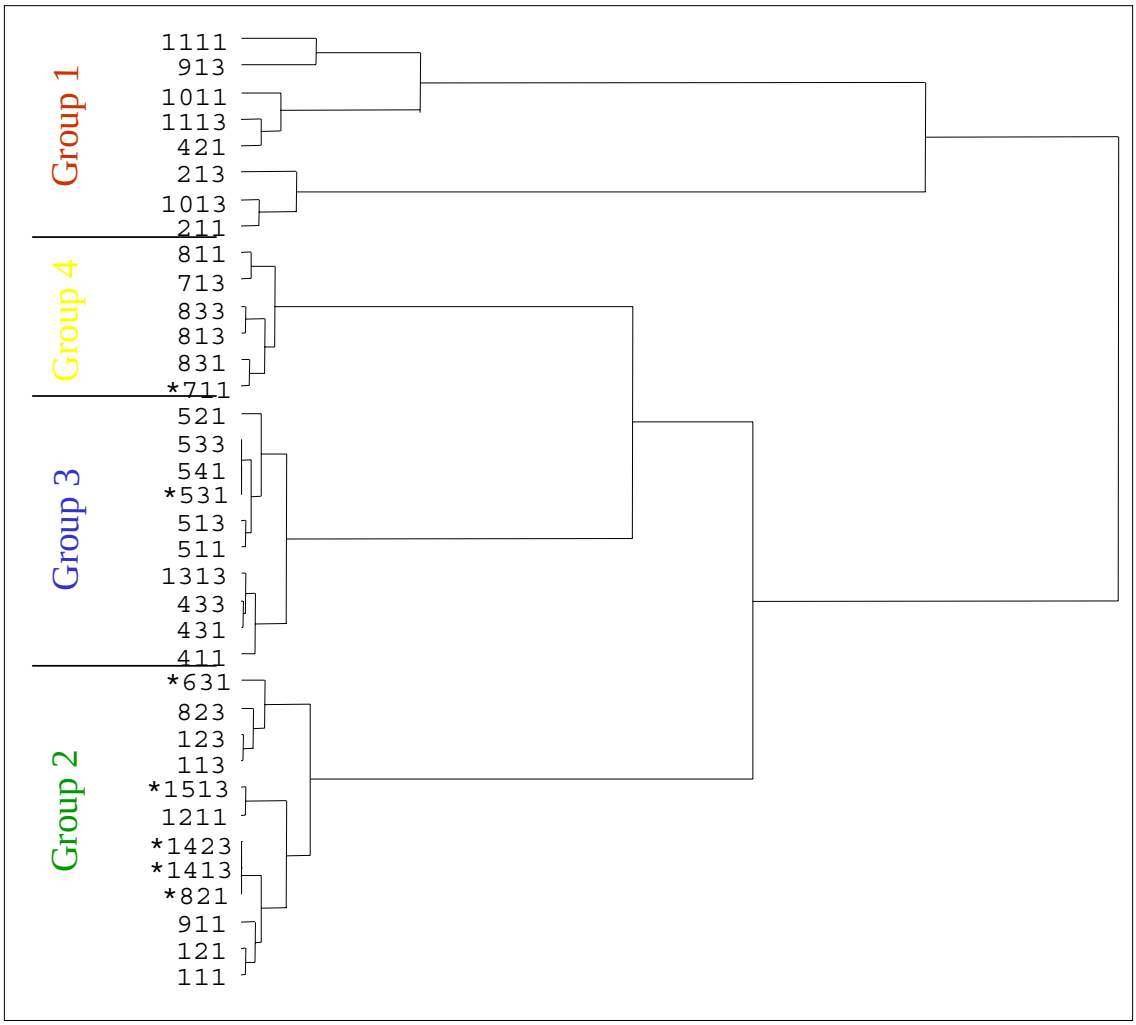


FIGURE 34. **Cluster analysis using Euclidean distance and Ward method, from Correspondence Analysis performed with macroinvertebrates abundance.* shows reference samples.**

In the last group, **group 4**, there are:

- 4 samples which were located downstream a logging road, two 50 meters and two 100 meters downstream. They were all taken on the same stream at 8 months time interval. The road was newly built in June-August 2000 when 811 (50 m) and 831 (100 m) were sampled. 8 months later, the logging activities were just finished when 813 (50 m) and 833 (100m) were sampled.
- 711 was a particular reference sample with a high proportion of bedrock. It is not known yet why it grouped here.

- 713 was sampled in the same station, after logging activities. At this site, part of the surrounding hill was clear cut just upstream and lot of sediment were found in the stream. This effect could be similar to the one encountered at 811, 813, 831 and 833 locations.

This group will be referred to as **group yellow**, with most **"open to sun"** samples downstream logging roads.

These four groups of samples were kept, accepting the fact that a "less detailed" level was chosen in order to have enough samples per group to allow between groups comparisons.

In summary, Correspondence Analysis highlighted the importance of stream size and the complexity of faunal composition. Cluster analysis underlined the importance of stream size too, but separated a first cluster group on the basis of the logging activities (**red**) with most samples 1 to 3 years after logging. Among the three other groups, one contained most reference samples (**green**), and between the two last groups, one assembled samples recently logged and open to sun (**yellow**) and the other all larger streams > 6m (**blue**).

6.2.8 Faunistical composition of cluster groups

Contributions from the taxa were calculated on the basis of their relative abundance in each cluster. Only taxa which contributed positively or negatively to the cluster groups are listed in table 21. Groups are organised in the following way:

group blue: all streams > 6 m width

group green: reference samples mixed with other samples

group yellow: samples during and 6 months after logging, downstream a logging road and sites with high erosion rate

group red: mainly samples between one and three years after logging activities

TABLE 21. List of taxa contribution to each cluster group, expressed in percentage of total inertia: positive contribution (+); negative contribution (-). Cells without number means a contribution of 0. Gr. blue (streams > 6m), Gr. green (most reference streams), Gr. yellow (open streams) and Gr. red (most disturbed streams).

Order	Family	Genera	Gr blue	Gr green	Gr yellow	Gr red
Coleoptera	Elmidae		+ 2			- 3
	Psephenidae				+ 8	- 6
	Scirtidae			+ 3		- 1
Diptera	Athericidae			+ 1		
	Chironomidae			- 1	+ 3	- 1
	Limonidae			+ 2	- 1	- 1
	Simuliidae		- 2	- 3	- 1	+ 15
Ephemeroptera	Baetidae	Cloeodes	+ 2	- 1		
		Genus 2			+ 1	
		Genus 4	+ 1	- 3		- 1
		Genus 5	+ 1	- 1		
		Jubabaetis	- 5	- 3	+ 25	

TABLE 21. (Continued) List of taxa contribution to each cluster group, expressed in percentage of total inertia: positive contribution (+); negative contribution (-). Cells without number means a contribution of 0. Gr. blue (streams > 6m), Gr. green (most reference streams), Gr. yellow (open streams) and Gr. red (most disturbed streams).

Order	Family	Genera	Gr blue	Gr green	Gr yellow	Gr red
		Labiobaetis		+ 1	- 1	
		Platybaetis	+ 41	- 22	- 1	- 13
		Platybaetis probus			+ 1	
		Genus 3		- 1	+ 6	- 1
	Caenidae	Caenis			+ 1	
		Caenodes		+ 1		
		Genus 8	- 1	+ 2		
		Clypeocaenis				+ 1
	Ephemerellidae	Hyrtanella	+ 4	- 4		- 1
		Uracanthella	+ 3	- 1		- 1
	Heptageniidae	Atopopus		+ 2		
		Cinygmina	+ 4			- 2
	Leptophlebiidae	Euthraulus	+ 1	+ 6		- 7
		Habrophlebiodes		+ 2		
		Isca	- 1	- 1		+ 4
	Polymitarcyidae	Polyplocia		+ 1		
	Potamanthidae	Stygifloris		+ 2		
	Teloganodidae	Genus 12		- 3	+ 13	- 5
		Teloganodes		- 1	+ 4	- 1
Gasteropoda			+ 1		- 1	- 1
Heteroptera	Helotrephidae			+ 1		- 1
Lepidoptera			+ 2	- 6	+ 2	- 1
Megaloptera				- 1	+ 1	
Plecoptera	Perlidae		+ 5	+ 1	- 2	- 7
Trichoptera	Glossossomatidae			- 1	+ 2	
	Helicopsychidae		+ 3		- 1	- 1
	Hydropschidae	Diplectroninae	- 1	- 1	+ 1	+ 2
		Hydropsychinae	+ 2	- 5		
		Hydropsychinae 1			- 2	+ 3
		Hydropsychinae 2			- 4	+ 3
		Hydropsychinae 3		- 2	+ 11	- 1
		Hydropsychinae 4	+ 1			
		Hydropsychinae 5	+ 1	- 1	+ 1	
	Hydroptilidae		+ 1	- 1		
	Macronematidae		+ 1			- 1
	Philopotamidae		+ 2			- 3
	Polycentropodidae			+ 1		
	Psychomyidae		+ 1	- 1		
	Xyphocentronidae			- 1	+ 2	- 2
Tricladia				+ 3		- 2
Zygoptera	Euphaeidae				+ 1	

The faunistical composition for each group is presented below. Positive and negative contribution superior to 2 were kept to make a faunistical list for each group.

Group blue (streams > 6m):

26 taxa contributed to this group containing all large streams. 21 positive contributing taxa with *Platybaetis* ahead and only 5 negative one, with *Jubabaetis* as highest negative score.

Positive contributions: *Platybaetis*; Perlidae; *Cinygmina*; *Hyrtanella*; Helicopsychidae; *Uracanthella*; *Genus 4* (Baetidae).

Negative contributions: *Jubabaetis*; Simuliidae.

The only taxon which contributed positively to this group with no contribution to the others group is Hydropsychinae 4.

There were several taxa that contributed positively to this group and negatively to the three others: Elmidae, *Cloeodes*, Baetidae *genus 4 and 5*, *Platybaetis*, *Hyrtanella*, *Uracanthella*, *Cinygmina*, Gasteropoda, Helicopsychidae, Hydropsychinae, Hydropsychinae 4, Hydroptilidae, Macronematidae, Philopotamidae and Psychomyidae, a majority of Trichoptera sub-families.

Group green (most reference streams):

On 39 contributing taxa, 15 contributed positively to the group, the highest score was *Euthraulus* (Leptophlebiidae). The other 24 taxa contributed negatively to this group, with particular high score for *Platybaetis* (Baetidae).

Positive contributions: *Euthraulus*; Tricladia; Scirtidae; *Potamanthus*; *Habrophlebiodes*; *Atopopus*; *Genus 8* (Caenidae) and Limonidae.

Negative contributions: *Platybaetis*; Lepidoptera; Hydropsychinae; *Hyrtanella*; *Genus 4* (Baetidae); *Genus 12* (Teloganodidae); Simuliidae; *Jubabaetis*; Hydrophsychinae3.

Several taxa contributed positively to this group only: Athericidae, *Caenodes*, *Atopopus*, *Habrophlebiodes*, *Polyplocia*, *Potamanthus* and Polycentropodidae: a majority of mayflies.

Scirtidae, Limonidae, *Labiobaetis*, *Euthraulus*, Helotrephidae, Perlidae and Tricladia all contributed positively to group green, but negatively to group yellow and red.

Group yellow (open to sun streams):

26 taxa contributed to this group, with 17 positive contribution and 9 negative ones. *Jubabaetis* (Baetidae) has the highest positive score and Hydropsychinae 1 the lowest negative one.

Positive contributions: *Jubabaetis*; *Genus 12* (Teloganodidae); Hydropsychinae 3; Psephenidae; *Genus3* (Baetidae); *Teloganodes*; Chironomidae.

Negative contributions: Hydropsychinae 2; Perlidae; Hydropsychinae 1.

Baetidae *genus 2*, *Platybaetis probus*, *Caenis* and Euphaeidae contributed positively to this group only: a majority of mayflies too.

Several taxa, such as Psephenidae, Chironomidae, *Jubabaetis*, *Genus 12* (Teloganodidae), *Teloganodes*, Glossossomatidae, Hydropsychinae 3 and Xyphocentronidae, had their "culminating" contribution in this group. Their contribution were low or negative in groups green and red.

Group red (most disturbed streams):

31 taxa contributed to this group. The situation was reversed compared to group yellow, with more negative contributing taxa (25) than positive ones (6). The highest positive contributing taxa was Simuliidae, whereas *Platybaetis* (Baetidae) was found again as lowest contributing taxon.

Positive contributions: Simuliidae; *Isca*; Hydropsychinae 2; Hydropsychinae 1; Diplectroninae.

Negative contributions: *Platybaetis*; *Euthraulus*; Perlidae; Psephenidae; *Genus 12* (Teloganodidae); Elmidae; Philopotamidae; *Cinygmina*; Xyphocentronidae.

One taxon contributed positively to this group only: *Clypeocaenis*.

Some taxa had positive or higher contribution to this group with negative contribution to the others: Simuliidae, *Isca*, Diplectroninae, Hydropsychinae 1 and 2.

In summary:

- group **blue (streams > 6m)**: highest positive contribution from *Platybaetis* and highest negative contribution from *Jubabaetis*;
- group **green (most reference streams)**: highest positive contribution from *Euthraulus* and highest negative contribution from *Platybaetis*; a majority of contribution form Ephemeroptera genera;
- group **yellow (open streams)**: highest positive contribution from *Jubabaetis, Genus 12* (Teloganodidae) *and Hydropsychinae 3*
- group **red (most disturbed streams)**: highest positive contribution from Simuliidae and highest negative contribution from *Platybaetis;* a majority of negative contribution

6.3 Relationships between stream habitat and its fauna

Environmental variables have been explored with a Principal Components Analysis and macroinvertebrate fauna with a Correspondence Analysis. Co-inertia is now used to explore the relationships between the habitat (environmental variables) and its aquatic fauna (the macroinvertebrates). This is the only way, according to Dolédec & Chessel (1994), to search for taxa-environment relationships when many variables (i.e. many taxa and several environmental variables) are sampled in few sampling sites (i.e. the number of environmental and faunistic variables is higher than that of samples).

We took the Correspondence Analysis previously obtained with the macroinvertebrates taxa (106 taxa) and the Principal Components Analysis with our 7 environmental variables we identified as pertinent. Co-inertia analysis is then processed using both analysis. To check significance of the resulting correlation between the two sets of coordinates, we use a 1000 random Monte-Carlo permutations test. The test is significant ($p<0.01$), meaning that habitat and macroinvertebrates are highly related to each other.

The co-structure described by co-inertia axes F1 and F2 is close to the structures of the data set described by axes F1 and F2 in the environmental (PCA) analysis and is a combination of the structures of the data set described by axes F1, F2 and F3 in the faunistic (CoA) analysis (Figure 35 c) and d)).

Figure 35 b) illustrate the environmental variables and their contributions to the co-inertia axes. Details of these contributions are given in table 22. Width, canopy opening and flow velocity mostly contribute to axis F1. Fine substrate, depth and OM ratio on the other hand, mostly contribute to axis F2. Water temperature is the only one to equally contributes to axes F1 and F2.

TABLE 22. Contributions of each environmental variables to the different factorial co-inertia axes F1 and F2. Numbers in show highest contributions.

Environmental variables	Contribution (%) to co-inertia axis F1	Contribution (%) to co-inertia axis F2
OM ratio	1.1	**26.5**
Width	**30.1**	0.01
Depth	10.4	**27.5**
Flow velocity	**17.3**	0.2
Water temperature	*8.94*	*8.2*
Canopy opening	**28.9**	6.6
Fine substrate	3.2	**30.9**

Figure 35 a) illustrates the 106 taxa. We choose to illustrate them by orders in figure 36. The following taxa are distributed along axes F1 and F2:

- on the right side of axis F1, where the streams are **narrow, flow velocity is low, the canopy is closed and water temperature cooler**, we find: Scirtidae (b); Psychodidae (c); crabs (d); Leuctridae and Peltoperlidae (e); Calamoceratidae and Polycentropodidae (f); *Genus 11* (Leptophlebiidae), *Euthraulus* and *Habrophlebiodes* (h); *Genus 8* (Caenidae) *and Caenodes* (i); *Atopopus* and *Genus 10* (Heptageniidae) (j); *Polyplocia* and *Potamanthus* (k) and *Liebebiella* and *Pseudocentroptiloides* (l)
- on the left side of axis F1, where the streams are **width, flow velocity is high, the canopy is open and water temperature is warmer**, we find: Lampyridae (b); Aphelocheridae and Lepidoptera (e); Psychomyidae and Hydroptilidae (f); Hydropsychinae 4 (g); *Genus 9* (Caenidae) (i); *Hyrtanella* and *Teloganella* (k); *Platybaetis* and *genus 5* (l).
- on the upper side of axis F2, where the **proportion of substrate composition is mostly fine substrate (< 6cm), the Organic Matter ratio is low and the water temperature is warmer**, we only find: Amphipterygidae (a); Georissidae (b) *Choroterpes* (h) and *genus 7* (l)
- on the down side of axis F2, where the **proportion of substrate composition is mostly > 6cm, the Organic Matter ratio is high and the water temperature is cooler**, we find: Macromiidae and Lestidae (a); Hydropsychinae 7 (g); *Brachycercus* (i); *Nothacanthurus* (j); *Prosopistoma* and *Isonychia* (k); *genus 2* (l).

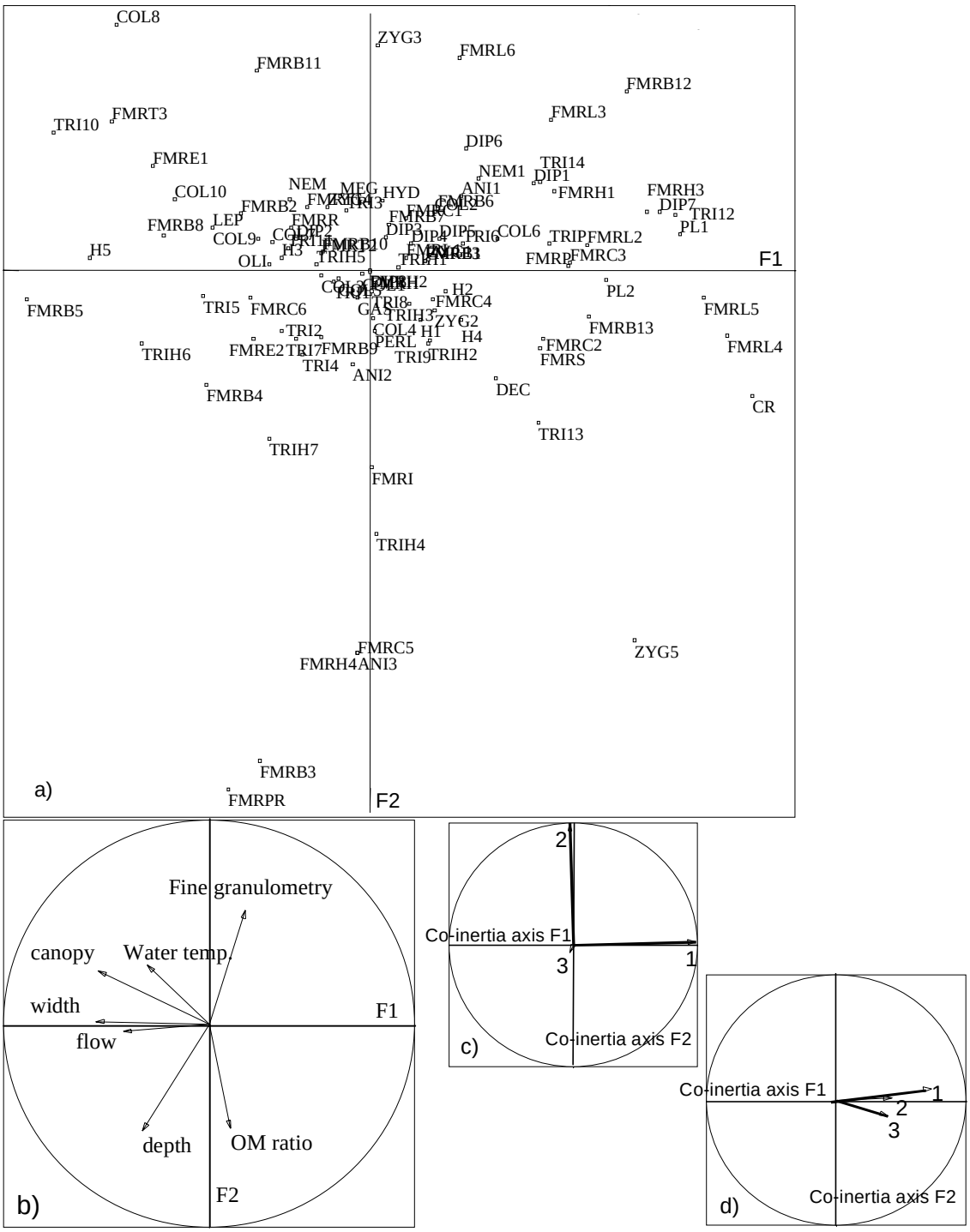
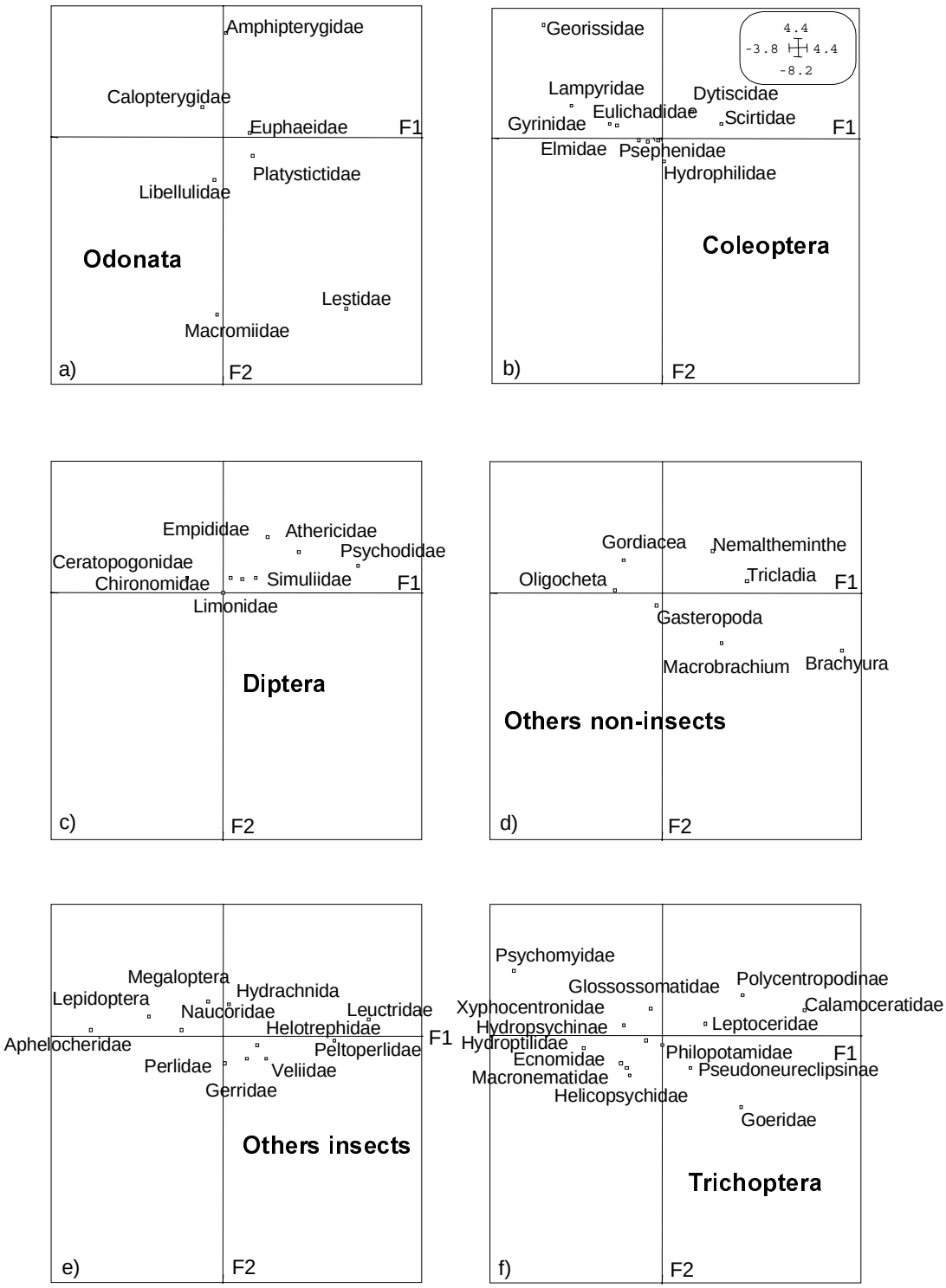


FIGURE 35. Co-inertia Analysis. (a) macroinvertebrate composition; (b) environmental variable with correlation circle; (c) and (d): each bold arrow represents axis F1, F2 and F3 of PCA with environmental variables projected on to the co-inertia axes (c) and of CoA with faunistic data projected on to the co-inertia axes (d).


Amphipterygidae
Calopterygidae
Euphaeidae
F1
Platystictidae
Libellulidae
Odonata
Lestidae
Macromiidae
a)
F2
Georissidae
4.4
-3.8
4.4
-8.2
Lampyridae
Dytiscidae
Eulichadidae
Gyrinidae
Scirtidae
F1
Elmidae
Psephenidae
Hydrophilidae
Coleoptera
b)
F2
Empididae
Athericidae
Psychodidae
Ceratopogonidae
Chironomidae
Simuliidae
F1
Limonidae
Diptera
c)
F2
Gordiacea
Nemaltheminthe
Oligocheta
Tricladia
F1
Gasteropoda
Macrobrachium
Brachyura
Others non-insects
d)
F2
Megaloptera
Hydrachnida
Lepidoptera
Naucoridae
Leuctridae
Helotrephidae
Aphelocheridae
Peltoperlidae
F1
Perlidae
Veliidae
Gerridae
Others insects
e)
F2
Psychomyidae
Polycentropodinae
Glossossomatidae
Xyphocentronidae
Calamoceratidae
Hydropsychinae
Leptoceridae
Hydroptilidae
Philopotamidae
F1
Ecnomidae
Pseudoneureclipsinae
Macronematidae
Helicopsychidae
Goeridae
Trichoptera
f)
F2

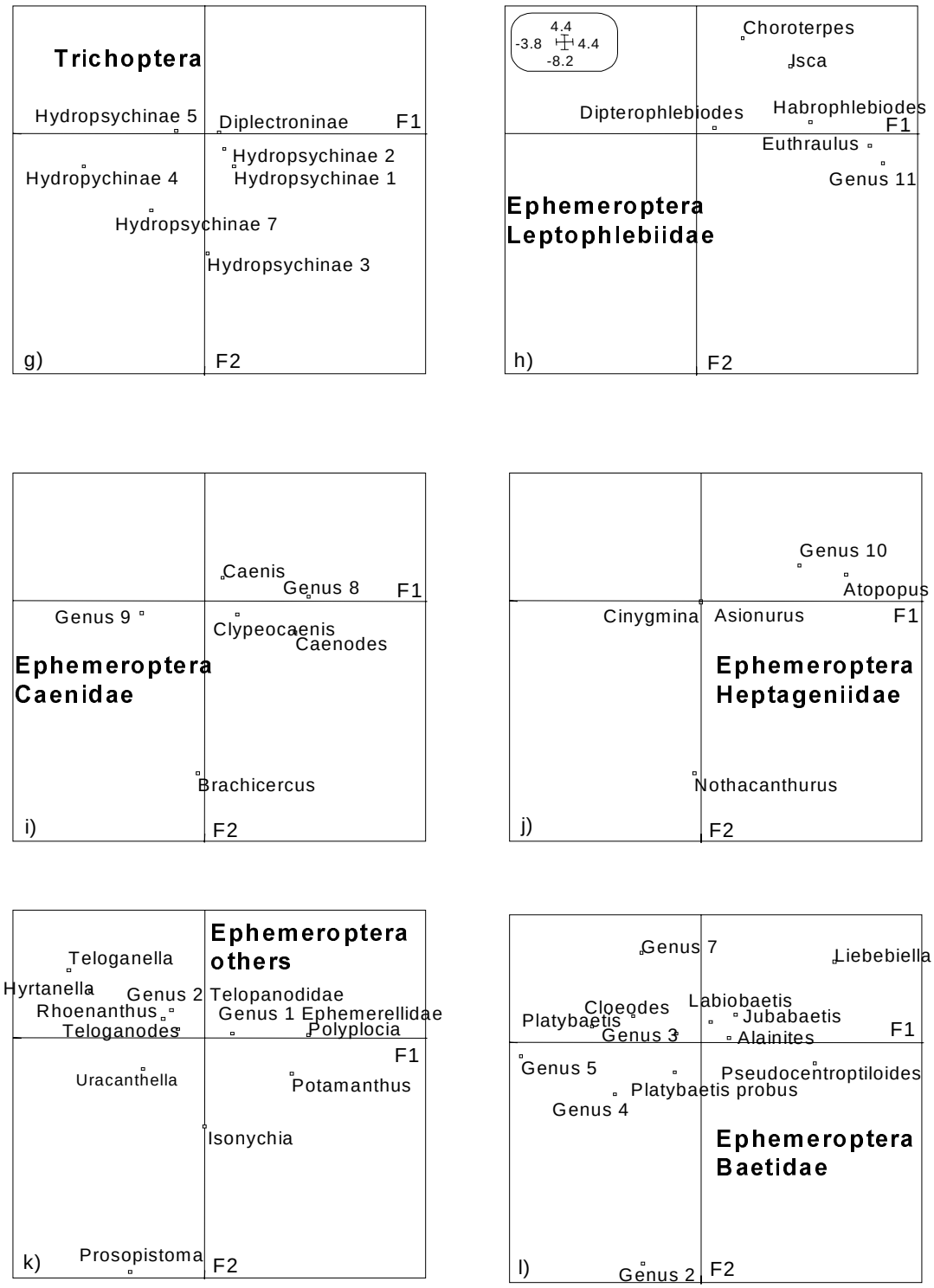


FIGURE 36. Graphs a) to f) illustrate the macroinvertebrate fauna from co-inertia analysis illustrated in fig. 35 a), but for each order or family at one time.

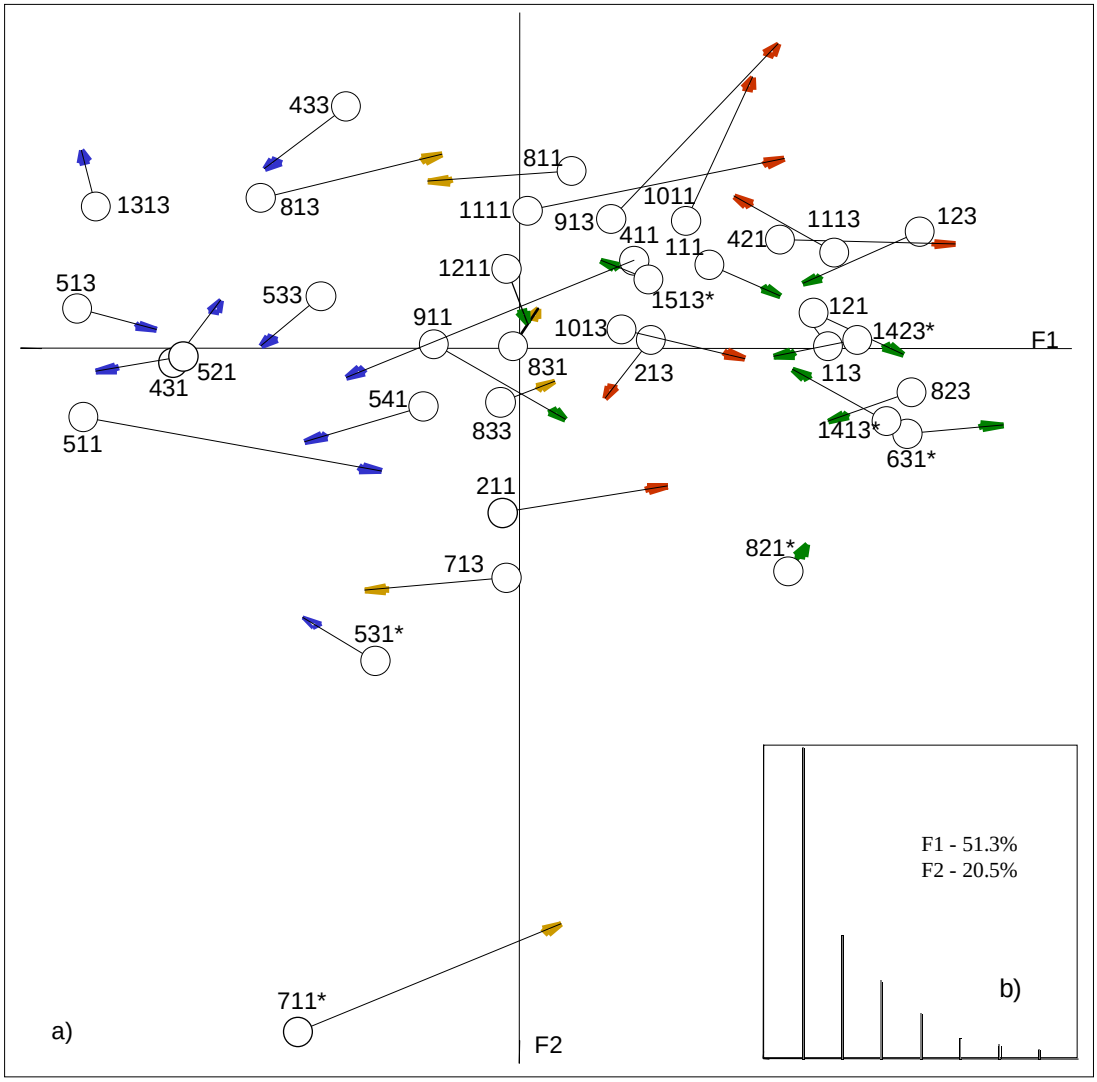


FIGURE 37. Positions of samples on the F1 x F2 co-inertia factorial plane (a). Circles indicate the position of samples resulting from the environmental variables and the end of the arrow, its position resulting from faunistic composition. Colours on arrows referred to colours used for cluster groups blue (streams > 6m), green (most reference streams), yellow (open streams) and red (most disturbed streams). (b) Histogram of eigenvalues.* reference sample

It is possible to discuss the correlation between the collected taxa and the streams environmental features by plotting the environmental (PCA) and faunistic (CoA) scores of the samples together on a factorial map (Figure 37) and to link the two positions of each sample by an arrow line. The circle indicates its position due to environmental variables and the end of the arrow its position due to fauna composition. For example, samples 811 and 813 yellow arrows in fig. 37 a) have different values of environmental variables (circles are separate) and close faunistic content (the arrows point to the same area). Samples 521 and 431 (in group blue) are in the reverse situation: they have similar environmental variables and different faunistic content.

The length of arrow's line indicates the "distance" to the mean co-structure proposed by the co-inertia. A short line: environmental variables and fauna are close to the mean "model" and are strongly related. This is the case for most undisturbed reference samples, indicated by *: 821, 1413, 1423, 1513, 631 and 531, with exception of sample 711. Disturbed samples, such as 913, 1011, 1111 (in the upper right quarter, end of arrow in red) have, in average, longer arrow's line, meaning that they are far from the mean co-structure proposed by the co-inertia.

The eigenvalue (Fig. 37 (b)) of the co-inertia analysis emphasizes the importance of the two first axes which explain 70.8% of the data structure.

6.4 Analysis by cluster groups

The cluster analysis took into account the stream size underlined by the PCA with environmental variables and by the CoA with macroinvertebrate composition. This is expressed by the group blue who included all streams larger than 6 meter width. The three other groups defined by the cluster analysis expressed other characteristics which are explored thereafter. The four cluster groups are compared and statistical differences are tested with Kruskal-Wallis ANOVA ranks test for environmental variables and macroinvertebrates diversity indices, EPT and feeding groups.

Table 23 presents the means, standard deviation (Std. Dev.) and standard error (Std. Er.) for each of the cluster groups blue, green, yellow and red. Depth, flow velocity, water temperature and canopy opening exhibited significant differences between cluster groups with Kruskal-Wallis ANOVA ranks test ($p<0.05$).

Significant differences with Kruskal-Wallis ANOVA ranks test between groups green, yellow and red was also tested as these results will be discussed later on, in chapter 8. Organic matter ratio, proportion of run and canopy opening are significantly differents.

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TABLE 23. Environmental variables with mean, standard deviation (Std. Dev.) and standard error (Std. Er.). *°# and § indicates that difference is significant with Mann-Whitney U-test ($p<0.05$) between the cluster groups.

Environmental variables	Gr. blue n=10 (streams > 6m)			Gr. green n=12 (most reference streams)			Gr. yellow n=6 (open streams)			Gr. red n= 8 (most disturbed streams)		
	Mean	Std. Dev.	Std. Er.	Mean	Std. Dev.	Std. Er.	Mean	Std. Dev.	Std. Er.	Mean	Std. Dev.	Std. Er.
Depth (m)	°0.47	0.21	0.03	°*0.26	0.09	0.02	*0.48	0.27	0.11	0.37	0.13	0.04
Flow velocity (m/s)	#°0.92	0.26	0.08	°*0.48	0.22	0.06	*0.72	0.17	0.07	#0.61	0.19	0.07
Water temperature (°C)	§°#25.74	0.67	0.2	°24.87	0.78	0.22	*#24.26	0.28	0.11	§*24.84	0.5	0.18
Air temperature (°C)	26.77	1.77	0.6	25.79	1.26	0.36	25.28	0.82	0.33	26.01	1.62	0.57
Conductivity (µs/cm)	#°*101.1	40.65	12.5	°53.95	37.07	10.7	*53.11	32.7	13.4	#45.73	46.5	16.4
Canopy opening (%)	§°35.23	21.1	6.7	°*8.6	5.3	1.5	*#28.8	13.9	5.7	§#11.9	7.1	2.5
Substrate composition (%):												
bedrock	°1.1	3.14	0.9	*1.3	3.1	0.9	°*20.8	31.9	13.0	11.6	22.1	7.8
boulder (>256 mm)	21.5	17.0	5.4	12.08	10.7	3.1	25.2	16.4	6.7	10.4	11.6	4.1
cobble (64-256 mm)	*37.5	12.7	4.0	33.7	23.6	6.8	*16.6	13.7	5.6	28.5	15.8	5.6
gravel (2-64 mm)	30.5	26.5	8.4	42.8	18.85	5.44	26	24.9	10.2	31.6	23.8	8.4
sand (0.06-2 mm)	*6.9	8.6	2.7	8.8	9.7	2.8	9.7	10.5	4.3	*12.3	13.0	4.6

TABLE 23. (Continued) Environmental variables with mean, standard deviation (Std. Dev.) and standard error (Std. Er.). *°# and § indicates that difference is significant with Mann-Whitney U-test (p<0.05) between the cluster groups.

Environmental variables	Gr. blue n=10 (streams > 6m)			Gr. green n=12 (most reference streams)			Gr. yellow n=6 (open streams)			Gr. red n= 8 (most disturbed streams)		
	Mean	Std. Dev.	Std. Er.	Mean	Std. Dev.	Std. Er.	Mean	Std. Dev.	Std. Er.	Mean	Std. Dev.	Std. Er.
siltclay (<0.06 mm)	3.0	4.2	1.3	1.3	3.1	0.9	1.7	2.6	1.1	5.6	13.4	4.9
substrate > 6 cm	60.1	24.6	7.7	47.1	23.4	6.7	62.7	33.4	13.6	50.5	15.5	5.5
substrate < 6 cm	40.4	24.4	7.7	52.9	23.4	6.7	37.3	33.4	13.6	49.5	14.5	5.5
Fine mineral Matter < 1 mm (gr)	28.3	17.6	5.6	*21.6	16.1	4.6	24.2	18.6	7.6	*38.7	17.7	6.2
Organic Matter FPOM (gr)	1.6	0.7	0.2	1.51	0.85	0.25	1.22	0.17	0.07	1.1	0.9	0.3
Organic Matter ratio (%)	°6.4	2.1	0.7	*8.86	4.21	1.21	8.42	6.7	2.7	°*3.03	2.15	0.76
Morphology types:												
small cascade (%)	0.0	0.0	0.0	3.3	8.8	2.6	3.3	5.1	2.1	4.5	8.9	3.2
riffle (%)	17.3	9.3	2.9	*14.3	13.2	3.8	*31.7	17.2	7.0	24.5	21.1	7.5
run (%)	53	21.7	6.9	*68.3	17.3	5.0	*36.7	25.8	10.5	45.5	31.6	11.2
pool (%)	28.7	25.4	8.0	13.3	17.0	5.0	30.0	35.2	14.4	25.5	25.5	9.0

6.4.1 Density, richness and diversity

Density, richness and diversity indices calculated for each faunistic cluster groups are presented in table 24. All values and indices were significantly different between groups blue, green, yellow and red with Kruskal-Wallis ANOVA by ranks test (p<0.05) and significantly different between groups green, yellow and red, except for the number of individuals.

The mean NUMBER OF INDIVIDUALS is at highest in group blue and at lowest in group red. Group green has closer values with group red, whereas group yellow has closer values with group blue.

TABLE 24. Mean richness and diversity indices with standard deviation (S.D) and standard error (S.E) compiled for each faunistic cluster group. Same symbol *°# and § show significant difference between groups with Mann-Whitney U-test (p<0.05).

	Group blue n=10 streams > 6m			Group green n=12 reference streams			Group yellow n=6 "open" streams			Group red n=8 disturbed streams		
	Mean	S.D	S.E	Mean	S.D	S.E.	Mean	S.D	S.E.	Mean	S.D.	S.E.
Nb of individuals (N)	*°1145	550	174	*573	284	82	887	445	182	°517	153	54
Nb of taxa (S)	*43	9	2.7	°36	11	3	38	10	4.2	*°26	8	3
Nb of taxa rarefaction	*34	4	1.2	°31	8	2.3	33	7	2.7	*°24	7	2.6
Alpha log series	*#12.07	1.72	0.54	*°13.84	3.26	0.94	12.42	2.06	0.84	°#8.71	3.94	1.39
Shannon H'	*2.84	0.34	0.11	°2.98	0.35	0.1	#2.95	0.3	0.12	*°#2.32	0.5	0.18
Shannon H' maximum	*3.73	0.20	0.06	°3.53	0.38	0.11	3.6	0.31	0.13	*°3.19	0.33	0.11
Pielou J	*0.76	0.07	0.02	*°0.84	0.05	0.02	0.82	0.07	0.02	°0.72	0.1	0.04
Modified Hill's ratio	8.95	4.29	1.35	*12.86	5.45	1.57	°12.58	4.29	1.75	*°6.04	4.5	1.6
Berger-Parker	*°0.27	0.09	0.03	*#0.19	0.09	0.03	°§0.17	0.05	0.02	#§0.34	0.16	0.06

NUMBER OF TAXA (S) and NUMBER OF TAXA with RAREFACTION: they both tend to be at highest in group blue and at lowest in group red, compared to the other groups. ALPHA LOG SERIES value is at lowest in group red, but at highest in group green. Among the three other groups with similar close values, mean values are more similar between group blue and yellow.SHANNON H' and H' MAXIMUM are at lowest in group red, with high difference between H' and H' max (0.87). This difference is of same order for group blue (0.89) with higher value of H' and H' max. Difference between H' and H' max is smaller for group green (0.55).

PIELOU J AND MODIFIED HILL'S RATIO. Group red has the lowest evenness indices. Group blue has lower evenness indices than groups green and yellow, but higher than group red. Both indices remain similar in group green compared to group yellow.

BERGER-PARKER DOMINANCE are highest in group red. It is higher in group blue versus groups green and yellow where values are similar.

In summary,

- group **blue** (streams > 6m) tends to have higher values in density (N), richness (nb of taxa (S) and nb of taxa after rarefaction) and with Shannon H' maximum compared to other groups
- in a successive sequence, from **green** (most reference streams) to **yellow** ("open" streams), and from **yellow** to **red**:
  - density and richness increase first and to decrease afterwards, but alpha log series values decrease immediately with logging
  - Shannon H' and H' maximum and both evenness (Pielou and modified Hill's ratio) indices remain constant from green to yellow and decrease in red
  - Berger-Parker remain constant from green to yellow and increase in red

6.4.2 Ephemeroptera, Plecoptera and Trichoptera (EPT)

In figure 38 a), EPT and "other" orders are represented by their relative proportion, for each cluster group, blue, green, yellow and red. Percentage EPT is high in average, with highest proportion in group blue (81%). This proportion remain constant in group green (71%) and group yellow (73%), but significantly decrease in group red (59%).

Group blue (larger streams) has the highest **Ephemeroptera** proportion compared to other groups. Compared to group green, Ephemeroptera proportion is higher in group yellow and lower in group red. **Plecoptera** have similar low proportion in groups blue and green, and at lowest in groups yellow and red. **Trichoptera** remain constant in groups blue, green and yellow and higher in group red. The "other" order, which are second dominant in proportion after Ephemeroptera in groups blue, green and yellow, become dominant in proportion in group red

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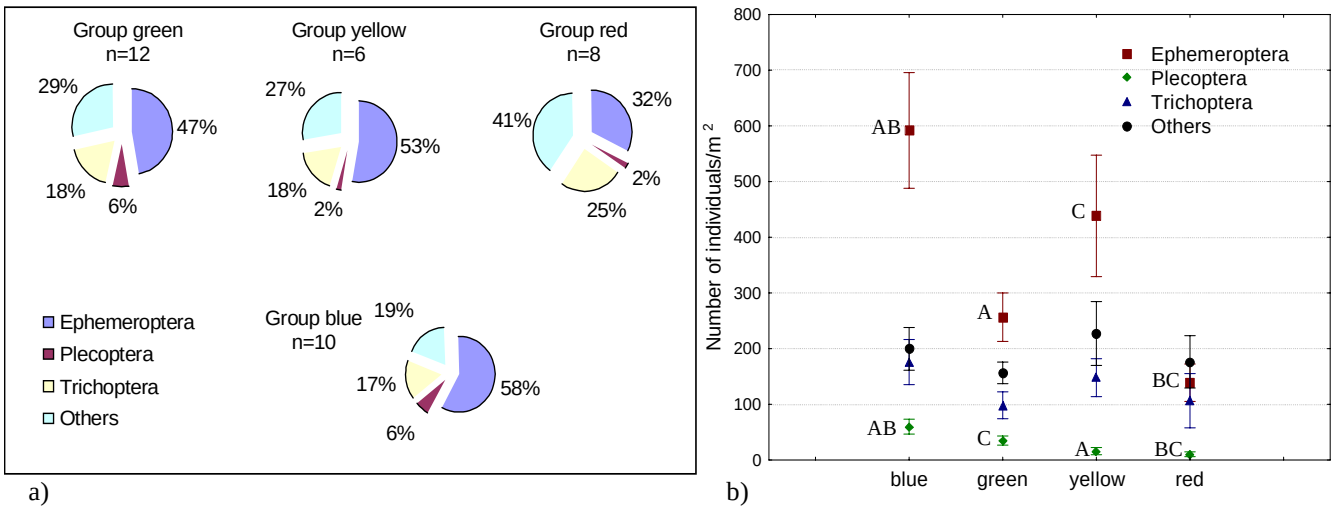

FIGURE 38. a) Ephemeroptera, Plecoptera, Trichoptera and "others" group are expressed in proportion from the average number of individuals for each cluster group. b) They are expressed in number of individuals per square meter with standard error bars, for each cluster group. Same capital letter indicates significant difference between groups with Mann-Whitney U-test (p<0.05).

In figure 38 b), there are significant differences between groups blue, green, yellow and red for Ephemeroptera and Plecoptera with Kruskal-Wallis ANOVA rank test (Ephemeroptera: KW(3, n=36)=14.065; p=0.0028 and Plecoptera: KW(3, n=36)=12.989; p=0.0047). Ephemeroptera is significantly different with Kruskal-Wallis ANOVA ranks test($p<0.05$) between groups green, yellow and red

Ephemeroptera density is dominant in all groups except in group red. Its density is at highest in group blue, higher in group yellow compared to group green and is at lowest in group red to be in lower density than the "other" orders. **Plecoptera** are in low density in all groups, but reach their highest density in group blue and their lowest density in group red compared to all other groups. **Trichoptera** density is similar in groups blue and yellow and lower, but similar in groups green and red. **"Other" orders** density follows same trend as Ephemeroptera and Trichoptera. It becomes dominant in group red.

In summary,

- Ephemeroptera is highest in proportion and density in all groups except in group red (most disturbed streams);
- Ephemeroptera, Trichoptera and "other" orders are all higher in density in group yellow (open streams) compared to group green (most reference streams), but quite similar in group red compared to green;
- Plecoptera are in lowest proportion and density in all groups, and are the only one to be lower in proportion and density in group yellow compared to group green;
- "Other" orders are second in proportion and density in all groups, except in group red

6.4.3 Functional feeding groups

Functional feeding groups are proportionally represented for each four cluster groups in figure 39. Relative abundance of **predators** is at highest in group green and at lowest in group yellow and red. The proportion of **grazers-scrapers** is dominant in all groups except in group red. They are similar in groups yellow and blue with more than 40%. **Omnivorous** encompassed omnivorous feeding groups, but as well mixed functional feeding groups such as, filtrer-predators, shredder-predators and shredder-scrappers. The proportion remain similar in groups blue, green and yellow and is at highest in group red where it becomes dominant.

Detritivorous proportion as a whole (shredders, filtrers and collectors) is at lowest in group blue (24%) compared to other groups, but remains more or less similar in groups green (36%), yellow (34%) and red (38%). The proportion of **shredders** is very low in all groups, but is higher in group blue. **Filtrers** proportion is at highest in group red and similar in groups yellow and blue. **Collectors** proportion is similar in groups green and yellow and at lowest, but similar in group red and blue.

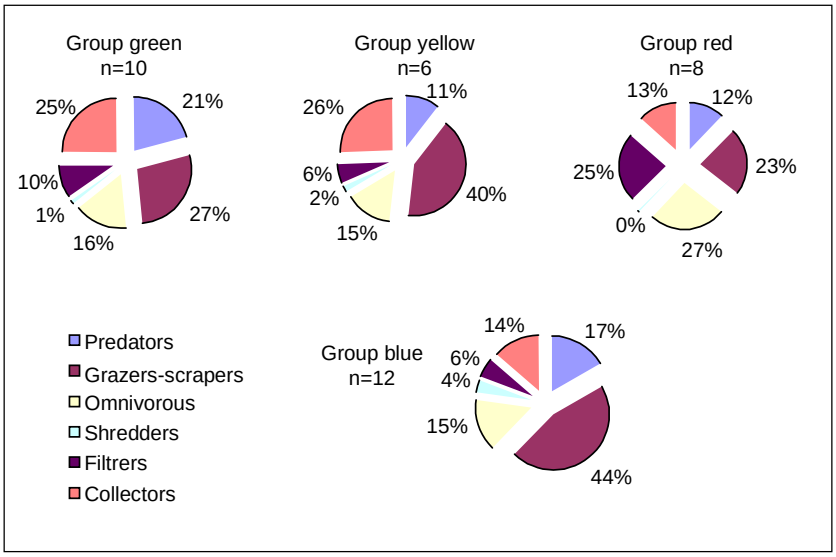

FIGURE 39. **Functional feeding groups expressed in proportion from the average number of individuals for each cluster group: green (most reference streams), yellow (open streams), red (most disturbed streams) and blue (streams > 6m)**

Figure 40 a) and b) illustrates the mean density for functional feeding groups predators, grazers-scrapers, omnivorous and detritivorous for each cluster groups. Significant differences are observed with Kruskal-Wallis ANOVA rank test for predators, grazers-scrapers and shredders (predators: KW(3, n=36)=14.23; p=0.0026; grazers-scrapers: KW(3, n=36)=16.98; p=0.0007 and shredders: KW(3, n=36)=10.48; p=0.015). Significant differences are observed for grazers-scrapers and collectors between groups green, yellow and red.

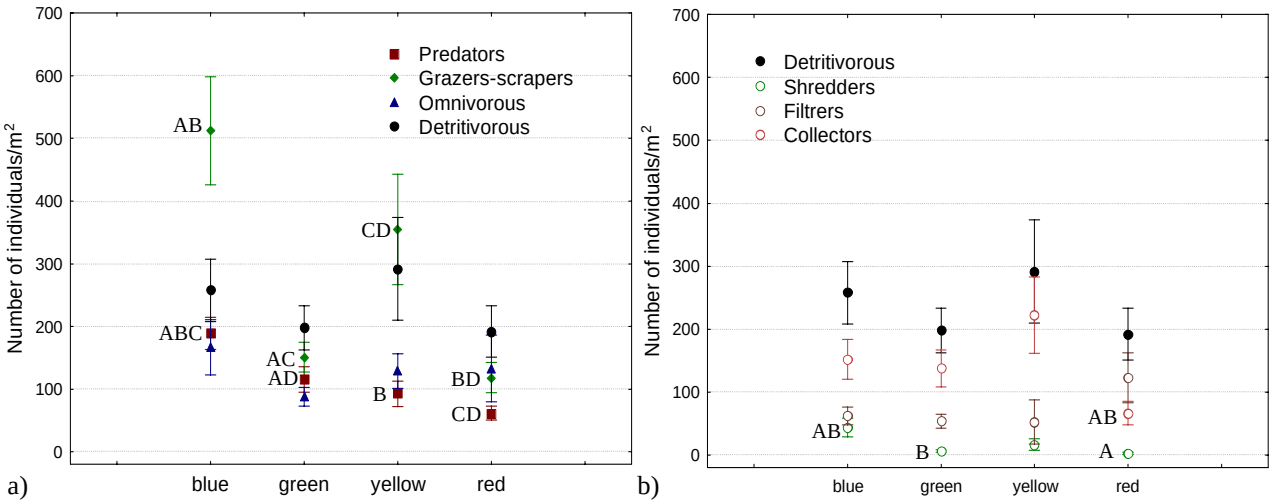

FIGURE 40. Functional feeding group are represented by mean number of individuals per square meter for each cluster group, blue (n=10), green (n=12), yellow (n=6) and red (n=8) with standard error bars. a) density of predators, grazers-scrapers, omnivorous and detritivorous are illustrated. b) density of detritivorous with its components, shredders, filtrers and collectors. Same capital letter for significant differences with Mann-Whitney U-test (p<0.05).

Predators density is rather low; at highest in group blue and at lowest in group red. **Grazers-scrapers** are dominant in groups blue and yellow. **Omnivorous** are in lowest abundance in groups blue and green. Their number are higher in groups yellow and red compared to group green, becoming more abundant than predators in both groups.

Detritivorous as a whole (shredders, filtrers and collectors) are dominant in groups green and red and in second position in group blue and yellow. **Shredders** are in very low density in all groups. **Filters** density is similar in groups blue, green and yellow and are at highest in group red where they become dominant as detritivorous. **Collectors** dominate in all groups except in group red.

In summary,

- **predators** have a mean proportion of 15%. They are the only feeding group to be lower in abundance in group yellow (open streams) compared to group red (most disturbed streams) when all the others feeding groups are higher in numbers, excepts the filtrers which remain similar compared to group green (most reference streams)
- **grazers-scrapers** are dominant in proportion (>40%) and abundance in both groups blue (streams > 6m) and yellow
- **omnivorous** have a mean proportion of 15%. Their density is higher in group yellow compared to group green and similar in groups yellow and red
- **detritivorous** are dominant in proportion (~35%) and in abundance in both groups green and red. **Shredders** are poorly represented. **Filtrers** proportion and density are at highest in group red. **Collectors** is in lower proportion (13%) in groups blue and red.

CHAPTER 7

Impact of logging activities on ecological water quality

In this chapter, the impact of logging activities on ecological water quality defined by stream habitat (described by environmental variables) and by macroinvertebrate fauna is examined.

The following hypotheses were tested:

Hypothesis 1: in the study site, logging activities change environmental variables at reach scale

Hypothesis 2: in the study site, logging activities change macroinvertebrate composition and functional organisation at habitat scale

For each of the main hypothesis, several hypotheses were formulated according to litterature. To simplify the phrasing, the literature references on which the hypotheses were based, was not mention here. These references will appear in the following discussion chapter. Data and results were confronted against each of these hypotheses.

A comparison of logging activities was only possible for streams smaller than 6 meters (see Table 8, "Number of samples per stream size and per status. One sample being the composite of three Surber net.," on page 44). Thus, the 26 samples on streams < 6 m were used to test the above mentioned hypotheses.

The groups defined by the cluster analysis in the previous chapter were based on macroinvertebrates composition. They did not give indication about the chronological sequence after logging operations; about what happened during logging, 1 to 3 years after logging, 4 to 5 years after logging or about relogging effect. As a consequence, the 26 samples are examined in this chapter according to their date of logging:

- a: reference samples (n=6) grouped all unlogged samples
- b: during and 6 months after logging (n=8)
- c: 1 to 3 years after logging (n=7)

- d: 4 to 5 years after logging (n=3)
- e: sampling sites 4 and 5 years after logging that started to be logged upstream the samples for a second time (n=2)

7.1 Environmental variables

Hypothesis 1: in the study site, logging activities change environmental variables at reach scale

Hypothesis 1a): logging activities have reported impacts such as increasing sediment load in the rivers, which could lead to decreasing depth and increasing flow velocity

Amount of **sediment** load are illustrated in figure 41 a) and b) with two different variables, substrate < 6cm (gravel, sand and silt-clay) and fine mineral, which is the mean mineral fraction inferior to 1 mm, collected with the Surber net for each sample.

Substrate < 6 cm: Kruskal-Wallis ANOVA ranks test show significant difference (KW(4, n=26)=10.42; p=0.034) between groups. Compared to reference samples a), fine substrate tends to be higher during logging activities in b) (road effect) and 1 and 3 years after logging (group c); it is significantly higher 4 to 5 years later, d) and when relogging activities occurred, e). Compared to 1 to 3 years after logging, the composition in fine substrate is significantly higher in groups d) and e).

Fine mineral quantity (<1mm): there is a significant difference with Kruskal-Wallis ANOVA (KW(4, n=26)= 9.73; p=0.045). Fine mineral quantity tends to be higher in c), 1 to 3 years after logging, compared to a), but is significantly lower in e), during relogging activities. Fine mineral quantity is also significantly lower in e) compared to during logging and 6 months after in b) and 1 to 3 years after logging in c).

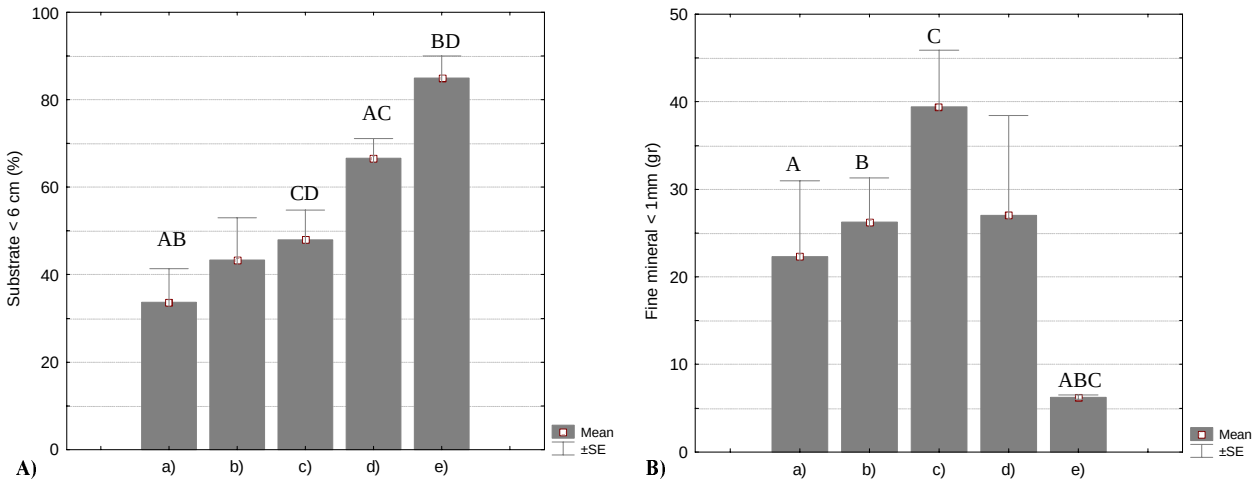

FIGURE 41. **A) substrate < 6cm groups the three substrate categories: gravel, sand, silt-clay estimated at reach scale. B) fine mineral < 1mm is the mineral fraction collected with the Surber net. All samples belong to < 6m stream size, n=26. a): reference sites (n=6); b): during logging and 6 months after (n=8); c): 1 to 3 years after logging (n=7); d): 4 to 5 years after logging (n=3); e): sampling sites 4 and 5 years after logging that started to be logged again (n=2). Same capital letter for significant difference between groups with Mann-Whitney U-test (p<0.05)**

Both substrate < 6cm and fine mineral quantity have same trend from a) to c), but differ in d) and e). Groups d) and e) can be considered as different from the other samples, with a high natural composition in substrate < 6 cm. It has to be remind that group d) is composed by 3 samples and group e) by 2 samples only. Nevertheless, even if group d) is different from the others (a, b and c), the impact of relogging activities is illustrated with the increase in substrate < 6 cm from d) to e). This may not appear with the quantity of fine mineral < 1mm, as during the first step of logging, the granulometry of sediment input was expected to be > 1 mm

Depth and flow velocity, as illustrated in figure 2, are not significantly different with Kruskal-Wallis ANOVA ranks test (p=0.148 and p=0.055 respectively).

Mean depth are similar in group a), b) and c) and streams are shallower in groups d) and e). From previously observation, both groups d) and e) had high composition in fine substrate (<6cm) as well.

Mean velocity tends to be slightly higher during logging (b) compared to a). Groups d) and e) have lower velocity, which is consistent with low depth and high fine substrate.

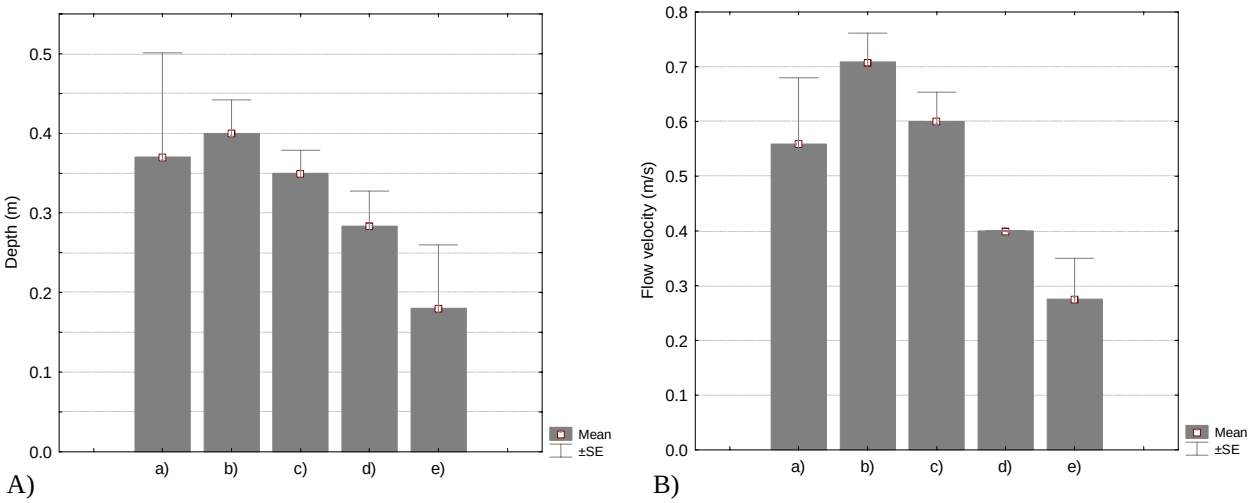

FIGURE 42. **A) mean depth (m) and B) flow velocity (m/s) for each group a, b, c, d and e. All samples belong to < 6m stream size. a): reference sites (n=6); b): during logging and 6 months after (n=8); c): 1 to 3 years after logging (n=7); d): 4 to 5 years after logging (n=3); e): sampling sites 4 and 5 years after logging that started to be logged again (n=2).**

In summary, **hypothesis 1a)** that logging activities have reported impacts such as increasing sediment load in the rivers, which could lead to decreasing depth and increasing flow velocity, **is partly validated with these data**.

- fine substrate (sediment < 6 cm) and fine mineral (<1mm) quantity are significantly different between groups. High values where observed in group c), 1 to 3 years after logging. Groups d) and e) are characterised by higher composition in fine substrate, lower sand quantity, lower depth and lower flow velocity. It is difficult to affirm that this is due to logging activities rather than natural features, considering the low number of samples (d: n=3 and e:n=2).
- Depth and flow velocity are not significantly different between groups.

Hypothesis 1b): by harvesting trees, logging activities reduce trees density along stream side and by opening of the canopy. A potential consequence is the increase of incident light into streams, which may cause water temperature to increase

Canopy opening (fig. 43, A): there is no significant difference with Kruskal-Wallis ANOVA ranks test (p=0.14). Canopy opening is higher during logging activities (group b) compared to the other groups, but is lower 1 to 3 years after logging (group c), probably due to vegetation regrowth. 4 to 5 years after logging the initial vegetation cover is almost completed.

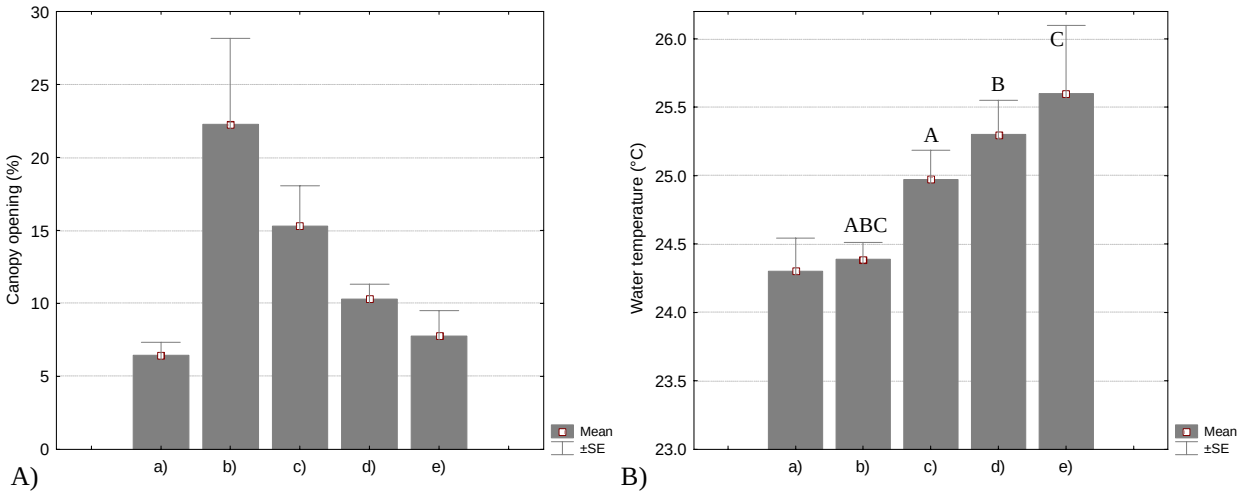

FIGURE 43. **Canopy opening (A) and water temperature (B) represented for each group a), b), c) d) and e). All samples belong to < 6m stream size. a): reference sites (n=6); b): during logging and 6 months after (n=8); c): 1 to 3 years after logging (n=7); d): 4 to 5 years after logging (n=3); e): sampling sites 4 and 5 years after logging that started to be logged again (n=2). Same capital letter indicates significant difference with Mann-Whitney U-test (p<0.05).**

Water temperature (figure 43, B) is significantly different between groups with Kruskal-Wallis ANOVA ranks test (KW-H(4,26)=11.24; p=0.024)).

Compared to a), water temperature is not higher during logging (b) when canopy opening is at highest, but is significantly higher 1 to 3 years after logging activities (group c), 4 to 5 years after logging (group d) and during relogging (group e). The fact that group b) has similar water temperature as group a) may be due to the fact that this group is constituted by samples taken during logging activities, downstream new logging road, but before harvesting of trees has been completed. Most of the watershed was still under vegetation cover. Even several years after logging (group c), d) and e)), the temperature is higher than reference sites (a).

.

In summary, **hypothesis 1b)**, by harvesting trees, logging activities reduce trees density by opening of the canopy. A potential consequence is the increase of incident light into streams, which may cause water temperature to increase, **is partly validated with these results**:

- canopy opening is higher during logging activities
- water temperature is significantly different between groups and higher 1 to 3 years after logging

Hypothesis 1c): a decrease in Organic Matter could be observed after logging activities due to less density or less regular input of material from the surrounding trees

Organic Matter (OM) content could first increase due to the amount of leaves, branches and woody material arriving in very short time into the streams during harvesting trees as part of logging activities. But this amount of material would be probably quickly taken away during rainy events, without having the time to be decomposed or reduced in size inferior to 1 mm. Organic Matter fraction <1mm, illustrated in figure 44 A) was collected with each Surber sample. Figure 44 B) illustrates Organic Matter ratio, as the proportion of this quantity of OM compared to the proportion of mineral fraction that was called fine mineral quantity <1mm (see fig. 41).

Fine Organic Matter quantity shows significant differences between groups with Kruskal-Wallis ANOVA ranks test (KW(4,26)=11.56; p=0.021). Compared to group a), organic Matter quantity is lower during logging activities (group b) and 1 to 3 years after logging (group c), as well as in group e), during relogging. It is similar in a), unlogged and in d), 4 to 5 years after logging.

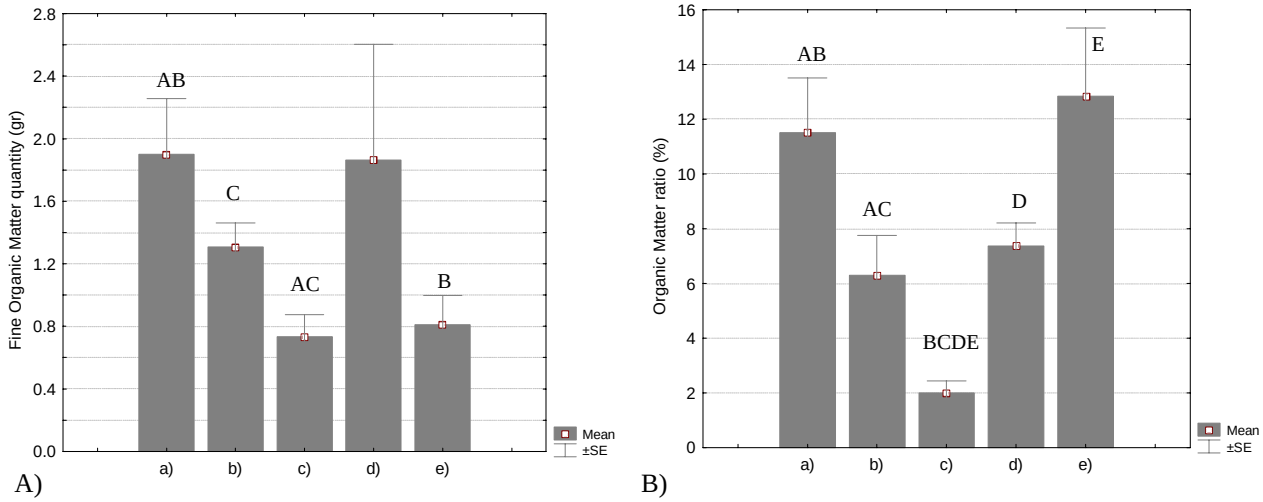

FIGURE 44. A) fine Organic Matter (gr) and B) Organic Matter ratio (%) are represented for each group a), b), c), d) and e) All samples belong to < 6m stream size. a): reference sites (n=6); b): during logging and 6 months after (n=8); c): 1 to 3 years after logging (n=7); d): 4 to 5 years after logging (n=3); e): sampling sites 4 and 5 years after logging that started to be logged again (n=2). Same capital letter indicates significant difference with Mann-Whitney U-test (p<0.05).

Organic Matter ratio shows significant difference between groups with Kruskal-Wallis ANOVA ranks test (KW(4,26)=17.5; p=0,0015). Organic Matter ratio has same trend than Organic Matter quantity, but more pronounced: it is lower during logging activities (b) and even lower 1 to 3 years after logging (c) compared to a). It is of similar proportion in b) and d), 4 to 5 years after logging and of similar proportion in a) and e), during relogging activities. Group (e) has divergent behaviour: OM quantity remains low, but OM ratio increases. As group (e) only contains 2 samples, it is difficult to discuss this trend.

In summary, **hypothesis 1c)**, a decrease in Organic Matter should be observed after logging activities due to less density or less regular input of material from the surrounding trees, **is validated** with these data:

- fine Organic Matter quantity and ratio decrease during and after logging activities, until 1 to 3 years after;
- 4 to 5 years after logging, the ecosystem starts to recover and both fine Organic Matter and ratio increase.

7.2 Macroinvertebrates fauna

Hypothesis 2: logging activities change macroinvertebrate composition and structure at habitat scale in the study site

7.2.1 Richness and diversity indices

Hypothesis 2a): macroinvertebrate density, richness and diversity are changing after logging activities

All indices exhibit significant differences between groups with Kruskal-Wallis ANOVA ranks test ($p<0.05$), except density (mean number of individuals/m^2).

DENSITY or MEAN NUMBER OF INDIVIDUAL (figure 45, A): density tends to be higher in group b), during logging and e), during relogging, compared to the other groups.

Richness is expressed by the NUMBER OF TAXA AFTER RAREFACTION which is represented in figure 45 B). We compared it with NUMBER OF TAXA (S) represented on the same graph. Both trends are similar, except in group e) where the number of taxa is lower than c) when the number of taxa after rarefaction is similar; the number of taxa tend to be higher in b) during logging activities, compared to a), is significantly lower in c) 1 to 3 years after logging, compared to a). Group c) has the significant lowest values compared to all other groups. a), b), d) and e) have all similar values.

ALPHA LOG SERIES (figure 45, C). This richness index, independent of sampling size effect, is more sensitive than the number of taxa after rarefaction as the differences between groups are higher in average. Group c) has significant lower values compared to all other groups.

MODIFIED HILL'S RATIO (figure 45 D), an evenness index, follows the same trend as observed with alpha log series, but c) and e) are not significantly different.

Dominance with BERGER-PARKER index and evenness with PIELOU J are illustrated on the same graph (figure 45 E). When dominance Berger-Parker index is high, evenness Pielou is low. Both remain similar in a), b), d) and e). Berger-Parker index is more sensitive with significant difference between b) and c).

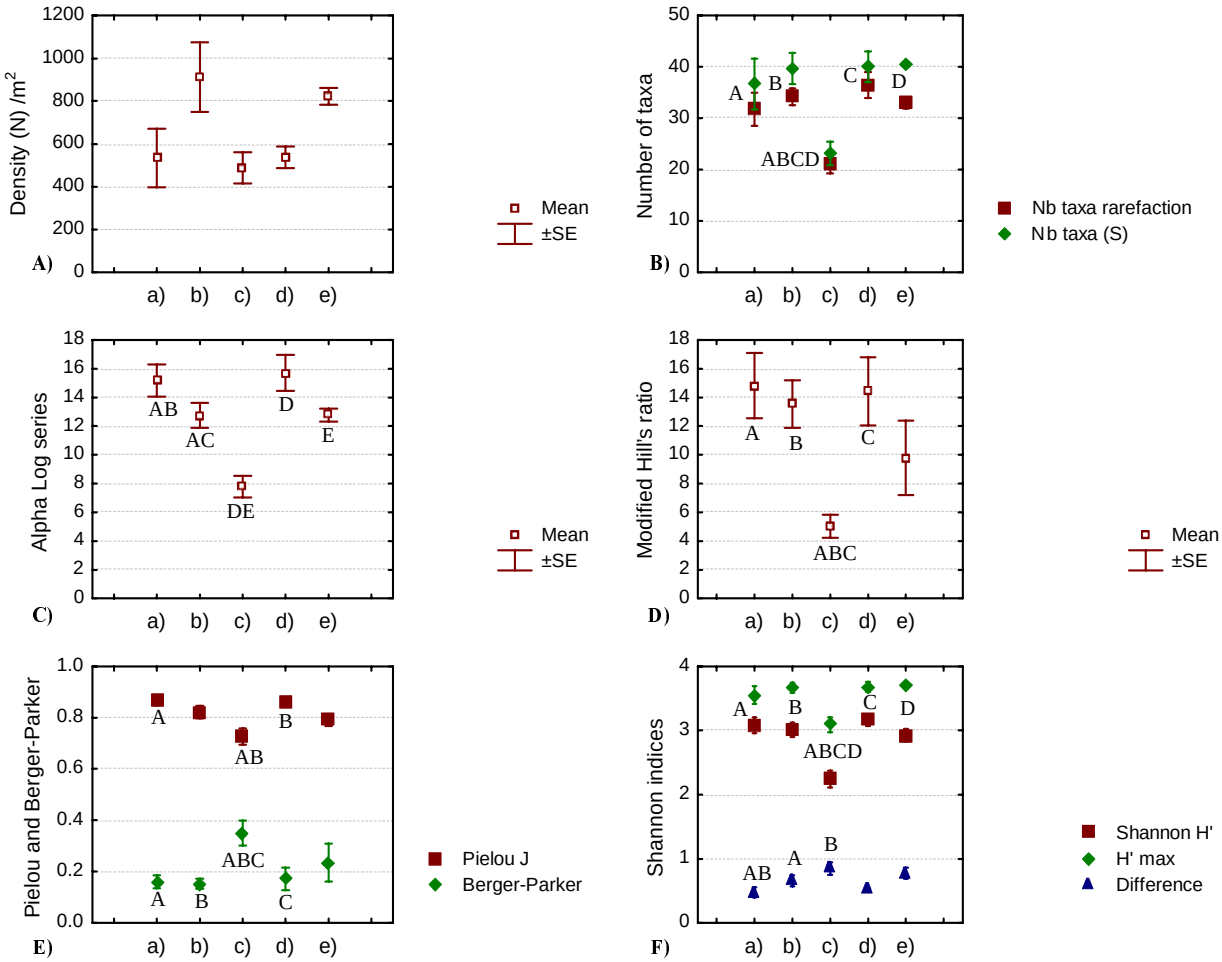

FIGURE 45. A) Number of individuals (N); B) number of taxa; C) alpha log series; D) Modified Hill's ratio; E) Pielou and Berger-Parker and F) Shannon H' and H' maximum are represented for each group a), b), c), d) and e). All samples belong to < 6m stream size. a): reference sites (n=6); b): during logging and 6 months after (n=8); c): 1 to 3 years after logging (n=7); d): 4 to 5 years after logging (n=3); e): sampling sites 4 and 5 years after logging that started to be logged again (n=2). Same capital letter indicates significant difference with Mann-Whitney U-test ($p<0.05$).

SHANNON H' and SHANNON H' MAXIMUM are illustrated in figure 45 F). Ln (S), with S the number of taxa, represents the expected maximum Shannon H' value. The difference between the expected Shannon H' maximum and Shannon H' values was calculated and illustrated. This difference is higher during and after logging, as well as 1 to 3 years after logging. This means that when disturbance increased, the difference between H' maximum and H' increased, suggesting that reference samples, group a) are closer to ideal situation where all species are represented by the same number of individuals (even distribution of abundance). Groups (a) 3.6, (b) 3.7, (d) 3.7 and (e) 3.7 have similar Shannon H' maximum values. Highest difference of 0.8 in group (c) highlights that group as the most disturbed one.

In summary, **hypothesis 2a)**, macroinvertebrate density, richness and diversity change after logging activities, **is partly validated**:

- 1 to 3 years after logging (group c), richness (Alpha log series), evenness (Modified Hill's ratio) and diversity (Shannon) are significantly lower (higher for Berger-Parker dominance) compared to a);
- 4 to 5 years after logging (group d), all values and indices seem to have "recovered" and are close to values encounter in reference group a);
- as soon as relogging activities start (group e), all values and indices tend to react, mostly by being lower (higher for density and Berger-Parker), but to a larger extent, such as if

7.2.2 Ephemeroptera, Plecoptera, Trichoptera (EPT) and other orders

Hypothesis 2b): percentage EPT is lower after logging activities

Relative proportion between the different orders are represented in figure 46. The more balanced situations, almost one third for each group Ephemeroptera, Trichoptera and other orders, appears in group a)..

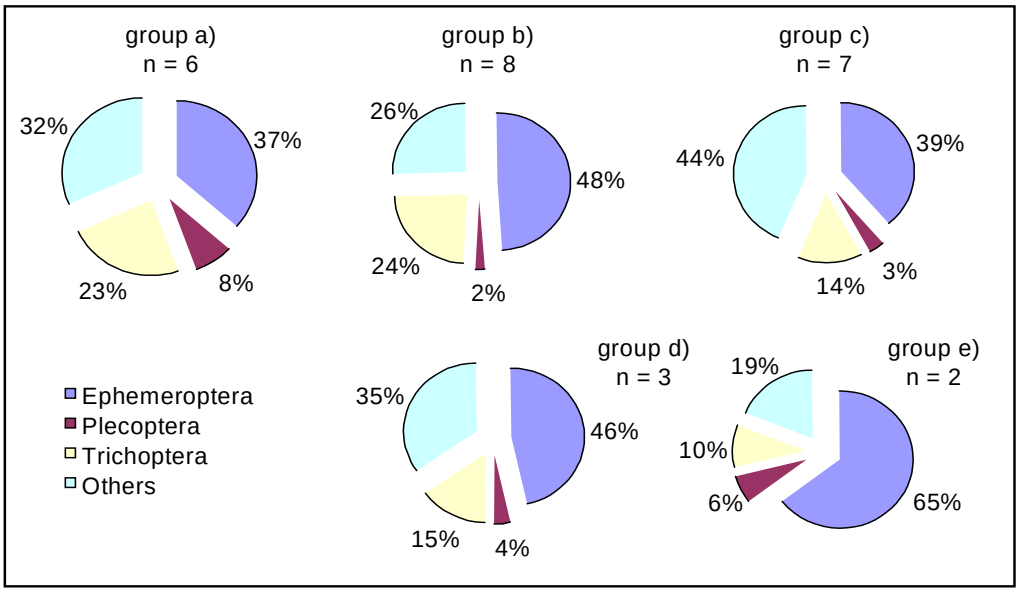

FIGURE 46. **Proportion of Ephemeroptera, Plecoptera, Trichoptera and other orders for each group a), b), c), d) and e). All samples belong to < 6m stream size. a): reference sites (n=6); b): during logging and 6 months after (n=6); c): 1 to 3 years after logging (n=9); d): 4 to 5 years after logging (n=3); e): sampling sites 4 and 5 years after logging that started to be logged again (n=2).**

When the proportion from the three groups is summed, Ephemeroptera, Plecoptera and Trichoptera, EPT% is obtained, an index used in bioassessment. This EPT percentage is: 68% in a); 74% in b); 56% in c); 65% in d) and 81% in e). EPT% is more similar between groups a) reference samples and d) 4 to 5 years after

logging. The observed trend is, higher proportion in b) compared to a), similar proportion in c) compared to a) and similar proportion in d) compared to b). Group e) has the highest proportion.

Ephemeroptera proportion dominates in all groups except in group c). It has the same trend as EPT%.

Plecoptera have low proportion in all groups, with highest proportion in group a).

Trichoptera have similar proportion in a), reference samples and b), during and 6 months after logging and lower but similar proportion in c), 1 to 3 years after logging and d), 4 to 5 years after logging. Group e), during relogging, has the lowest proportion of Trichoptera.

The **"other" orders** has the highest proportion in group c), 1 to 3 years after logging, where it becomes dominant. The proportion is similar in a) and d) and at lowest in e).

The mean density (number of individual/m^2) for each order and in each group are represented in figure 47. None of the groups are significantly different with Kruskal-Wallis ANOVA ranks test.

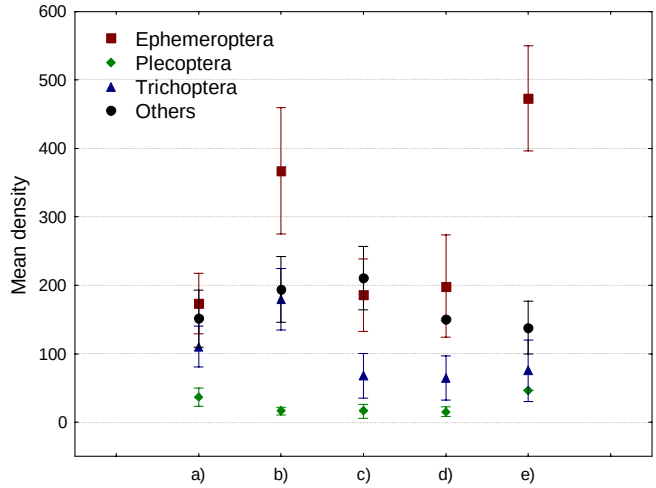

FIGURE 47. **Ephemeroptera, Plecoptera, Trichoptera and other orders are represented by mean individual per square meter with standard error bars, for each group a), b), c), d) and e). All samples represented here belong to < 6m stream size. a): reference sites (n=6); b): during logging and 6 months after (n=8); c): 1 to 3 years after logging (n=7); d): 4 to 5 years after logging (n=3); e): sampling sites 4 and 5 years after logging that started to be logged again (n=2).**

Ephemeroptera are dominant in all groups, except group c). **Plecoptera** are sensitive, their density is lower in all disturbed groups (b), c), d), but is high in e) with relogging activities. This is difficult to understand, unless they were sampled just before they started to be influenced by relogging. **"Other" orders** tend to slightly be higher in b), during and 6 months after logging and in c), 1 to 3 years after logging, compared to a), d) and e). "Other" orders is dominant in group c).

In summary, **hypothesis 2b)**, percentage EPT is lower after logging activities, **is partly validated for %EPT**. %EPT is higher during logging compared to unlogged and actually lower 1 to 3 years after logging. Moreover:

- Ephemeroptera plays an important role, both due to its dominant proportion compared to the other orders, and as well, due to its quick answer to logging activities by an higher density.
- Plecoptera are sensitive with lower density after logging activities, but its low number of individual make them less faithful (more sampling error).
- Trichoptera reflect longer time interval then Ephemeroptera, as it is still lower in density

7.2.3 Functional feeding group

Hypothesis 2c): functional feeding organisation (e.g. a lower number of detritivorous but an higher number of grazers-scrapers) is changing after logging activities

The relative proportion for each feeding group are represented in figure 48. None of the feeding group seems to be dominant, except the grazers-scraper in b), during and 6 months after logging and in d), 4 to 5 years after logging, and the collectors in e), during relogging activities. Shredders are the less represented feeding group.

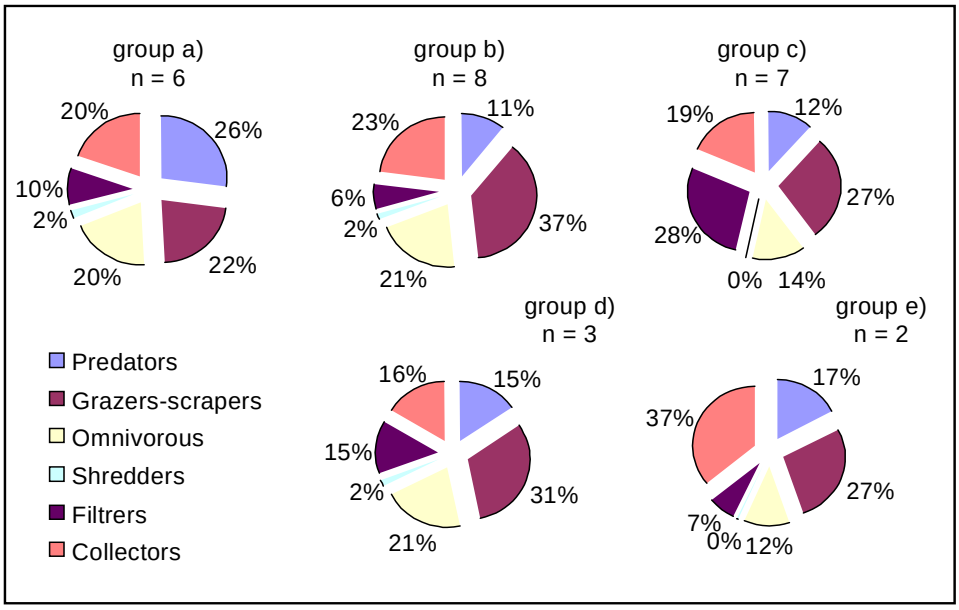

FIGURE 48. Macroinvertebrate relative abundance grouped by functional feeding group for each logging group a), b), c), d) and e). All samples represented here belong to < 6m stream size. a): reference sites (n=6); b): during logging and 6 months after (n=8); c): 1 to 3 years after logging (n=7); d): 4 to 5 years after logging (n=3); e): sampling sites 4 and 5 years after logging that started to be logged again (n=2).

Predators proportion is at highest in group a) and at lowest, but similar in groups b) and c). **Grazers-scrapers** proportion is at highest in b), during and 6 months after logging activities and d), 4 to 5 years after logging. Its proportion is at lowest in group a), reference samples. **Omnivorous** proportion is at lowest in groups c) and e). It is similar in group a), b) and d).

Detritivorous as a whole (shredder, filters and collectors) has similar proportion in a), reference samples (31%), in b) during logging (32%) and in d), 4 to 5 years after logging (33%). Its proportion is at highest in c), 1 to 3 years after logging (47%) and in e), during relogging (44%). **Shredders** remain constantly low (2% or less). **Filters** has highest proportion in c), 1 to 3 years after logging, and lowest proportion in b), during and 6 months after logging and in e), during relogging. **Collectors** has highest proportion in e), during relogging and lowest proportion in d), 4 to 5 years after logging.

Mean density (number of individual/m^2) for each feeding group is represented in figure 49. No significant differences appear between groups with Kruskal-Wallis ANOVA ranks test. Grazer-scrapers, omnivorous, and detritivorous in general, have all higher number of individual in group b), during and 6 months after logging compared to a), reference samples.

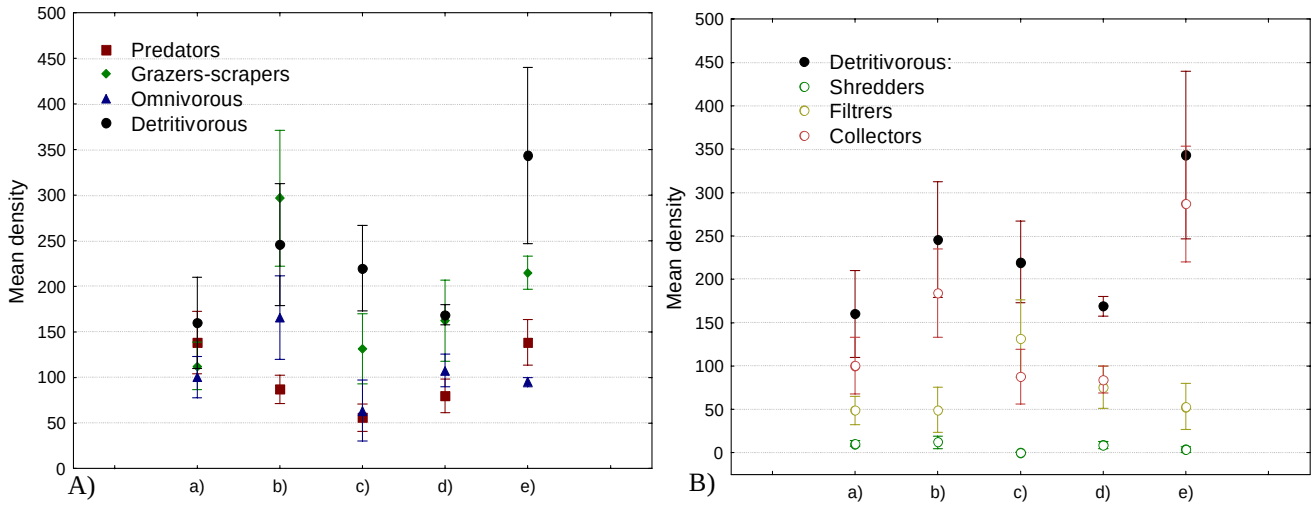

FIGURE 49. Functional feeding groups are represented by their mean number of individuals per sample with standard error bars. A) predator, grazers-scrapers, omnivorous and detritivorous as a whole; B) detritivorous is detailed with shredders, filters and collectors. All samples belong to < 6m stream size. a): reference sites (n=6); b): during logging and 6 months after (n=8); c): 1 to 3 years after logging (n=7); d): 4 to 5 years after logging (n=3); e): sampling sites 4 and 5 years after logging that started to be logged again (n=2).

Predators haves higher density values in a), reference samples and in e), during relogging. The lowest density is found in group c), 1 to 3 years after logging. Its proportion is low in b), during and 6 months after logging, and d), 4 to 5 years after logging, even when density of all other groups (i.e. potential preys) is higher. This is probably because the majority of the predator is composed by Plecoptera, which were found to be sensitive to logging (fig. 47).

Grazers-scrapers density is at highest in b), during and 6 months after logging and e) during relogging, and at lowest in a), reference samples.

Omnivorous density is at lowest in c), 1 to 3 years after logging activities, and at highest in b) during and 6 months after logging. Its density is similar in a), d) and e).

Detritivorous as a whole, has the highest density in e), during relogging and high density in b), during and 6 months after logging. This trend is mainly driven by **collectors** which are dominant in the detritivorous feeding group. **Filters** has the highest density in c), 1 to 3 years after logging. **Shredders** were found in low abundance, the lowest one compared to all others functional feeding groups. They seem to have the lowest density in c), 1 to 3 years after logging.

In summary, **hypothesis 2c)**, functional feeding organisation (e.g. a lower number of detritivorous but a higher number of grazers-scrapers) is changing after logging activities, **is validated**. A change in functional feeding organisation is observed: by a higher number of grazers-scrapers compared to a lower number a detritivorous during and 6 months after logging (group b)), but by a reverse situation in group c), 1 to 3 years after logging, where the number of detritivorous is higher than the number of grazers-scrapers.

CHAPTER 8

Ecological water quality and logging: discussion

The results obtained from the environmental variables describing the stream habitat and macroinvertebrates inhabiting it are discussed in this chapter. Whenever possible, they are compared with other regions of the world, they are confronted to theoretical existing "models" or "concepts" and they are examined at the light of logging activities.

First, results obtained with the cluster groups based on macroinvertebrate composition are compared with results obtained with logging groups based on time after logging. Then the cluster groups and the co-inertia analysis are examined together. Both analyses highlighted that a strong relationships linked the stream habitat and the macroinvertebrates, and moreover that the size of the stream played an important role, as well as the disturbance by logging activities.

In a second part, in order to discuss river size and logging effects, results obtained from the data are compared with longitudinal gradient concept, river continuum concept and disturbance theories. At the end of the chapter, some taxa identified as indicators of response to logging activities are described.

8.1 Comparisons between cluster and logging groups

In order to be able to compare cluster and logging groups, cluster groups green, yellow and red were considered. Group blue was left apart as it grouped all larger streams. Because of the absence of chronological logging sequence and their small numbers, samples belonging to stream more than 6 meter width were not taken into account (see table 8 on page 44, Material and Method). Thus, the effects of logging was examined on smaller streams grouped by time after logging (a, b, c, d and e) and results were presented in the previous chapter.

Group green (n=12) contained most reference samples as well as mixed samples, group yellow (n=6) contained most samples located downstream a logging road

with mixed samples 6 months after logging and group red (n=8) contained most samples 1 to 3 years after logging activities.

The logging groups represented a) reference samples only (n=6), b) during logging activities and 6 months after with samples downstream logging road (n=8), c) samples 1 to 3 years after logging only (n=7), d) samples 4 to 5 years after logging (n=3) and e) sampling sites 4 and 5 years after logging that started to be logged upstream the samples for a second time (n=2).

Table 25 underlines the similarities between the cluster groups green, yellow, red only based on fauna composition and the logging groups a, b, c, d and e based on chronological logging activities. All the 26 samples belonged to streams less than 6-meters width.

TABLE 25. Samples composition for each cluster group green, yellow, red and logging groups a, b, c, d and e.* indicates reference samples

Sample number	cluster groups			logging groups				
	green	yellow	red	a)	b)	c)	d)	e)
111	X						X	
113	X							X
121	X						X	
123	X							X
*631	X			X				
*821	X			X				
823	X					X		
911	X					X		
1211	X					X		
*1413	X			X				
*1423	X			X				
*1513	X			X				
*711		Y		Y				
713		Y			Y			
811		Y			Y			
813		Y			Y			
831		Y			Y			
833		Y			Y			
211			Z		Z			
213			Z		Z			
421			Z				Z	
913			Z			Z		
1011			Z			Z		
1013			Z			Z		
1111			Z			Z		
1113			Z			Z		

When comparing results obtained for **environmental variables** for both cluster and logging groups, it was found out that trends observed were similar, but that more environmental variables were statistically significant between logging groups than between cluster groups (table 26).

TABLE 26. Comparison between cluster groups green, yellow and red with logging groups a, b, c, d and e. Environmental variables and macroinvertebrate composition mentioned in the table are all significantly different with Kruskal-Wallis ANOVA ranks test (p>0.05).

Cluster groups (green, yellow and red)		Logging groups (a,b,c,d,e)	
Environ. variables	**Macroinvertebrates**	**Environ. variables**	**Macroinvertebrates**
Organic matter ratio	all diversity indices	Substrate <6cm	all diversity indices
Run percentage	Ephemeroptera density	Fine Mineral matter	
Canopy opening	Grazers-scrapers density	Water temperature	
	collectors density	Fine Organic Matter	
		Organic Matter ratio	

When comparing results obtained for **macroinvertebrate fauna density, richness and diversity**, significant differences and trends expressed by cluster groups and by logging groups were similar. In both cases, the mean number of individuals was the only value which was not significantly different. **Ephemeroptera, Plecoptera, Trichoptera and other orders**: difference were only significant between cluster groups for Ephemeroptera density. **Functional feeding groups**: significant difference were only observed between cluster groups for grazers-scrapers and collectors densities.

More significant differences were exhibited by macroinvertebrates between the cluster groups than between the logging groups, because the cluster analysis was based on macroinvertebrate composition. But, the fact that more significant differences were exhibited by environmental variables between the logging groups is more difficult to explain.

During this study, environmental variables were mainly used to describe the streams habitat for the macroinvertebrate fauna, to describe a frame, a picture of what was the environment of the macroinvertebrate sample at the sampling site on two sampling dates. Environmental variables were not measured on a regular basis, several times in a month or even weeks and days, and several times in a year, during several years

Whereas, macroinvertebrates allowed to give a perception on what happened along a certain time (life span depending on each taxa). Working with logging groups meant that history and chronological sequence about logging activities had to be known, which was not required when using cluster groups.

In conclusion:

- this comparison between cluster and logging groups allowed to propose that as trends observed are similar, these trends can be attributed to the impacts due to logging activities.
- results obtained with cluster groups faithfully represent the changes in environmental conditions (due to logging activities). This highlights the strength of macroinvertebrates as indicators of recent and past events.

8.2 Synthesis on environmental variables, macroinvertebrates and logging activities

The cluster groups and the co-inertia analyses highlighted that a strong relationship linked the river habitat, described by environmental variables, and the macroinvertebrate fauna inhabiting it, and moreover that river size played an important role as well as disturbance by logging activities.

With the previous conclusions in mind, figure 50 can be better understand. It represents the Correspondence Analysis (CoA) based on the macroinvertebrate composition with the four faunistical cluster groups, delimited by convex hulls. Group green is located in the middle of an imaginary circle linking groups yellow - green - red.

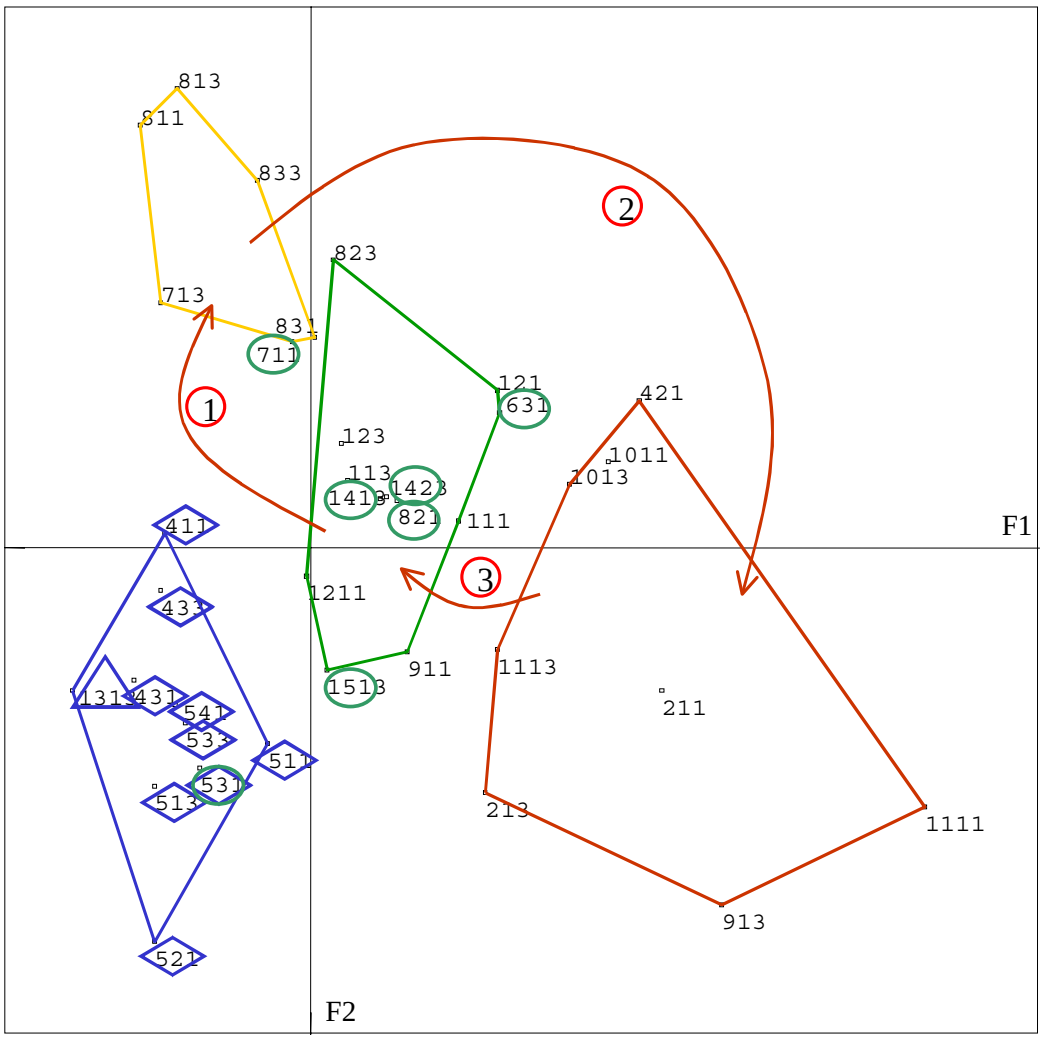

FIGURE 50. Correspondence analysis (CoA) on macroinvertebrate composition with convex hulls delineating the groups defined by the cluster analysis. Green circles are around reference samples, blue lozenges and triangle around river > 6m width. Red arrows represent the chronological sequence of the logging activities between the cluster groups green (most reference samples), yellow (open samples) and red (most disturbed samples). Group blue (streams >6m).

Group green contained the majority of reference samples and prefigured the reference situation. Considering the chronological sequence of the logging activities, the following observations can be made: during the first step 1) samples moved along this imaginary circle, on the upper left during logging activities and the first 6 months after. During the second step 2) samples then moved back, crossed the reference situation and continued on the down right, during 1 and 3 years after logging, depending on the logging intensity and original conditions. During the third step 3), the recovery process brought the samples back to starting situation, 4 to 5 years after logging. This could explain the presence in group green of the majority of reference samples (5 samples in green circles), but as well, 4-5 years after logging (111 and 121), relogging of 4-5 years after logging (113 and 123), 1 years after logging (1211 and 911) and 6 months after logging (823).

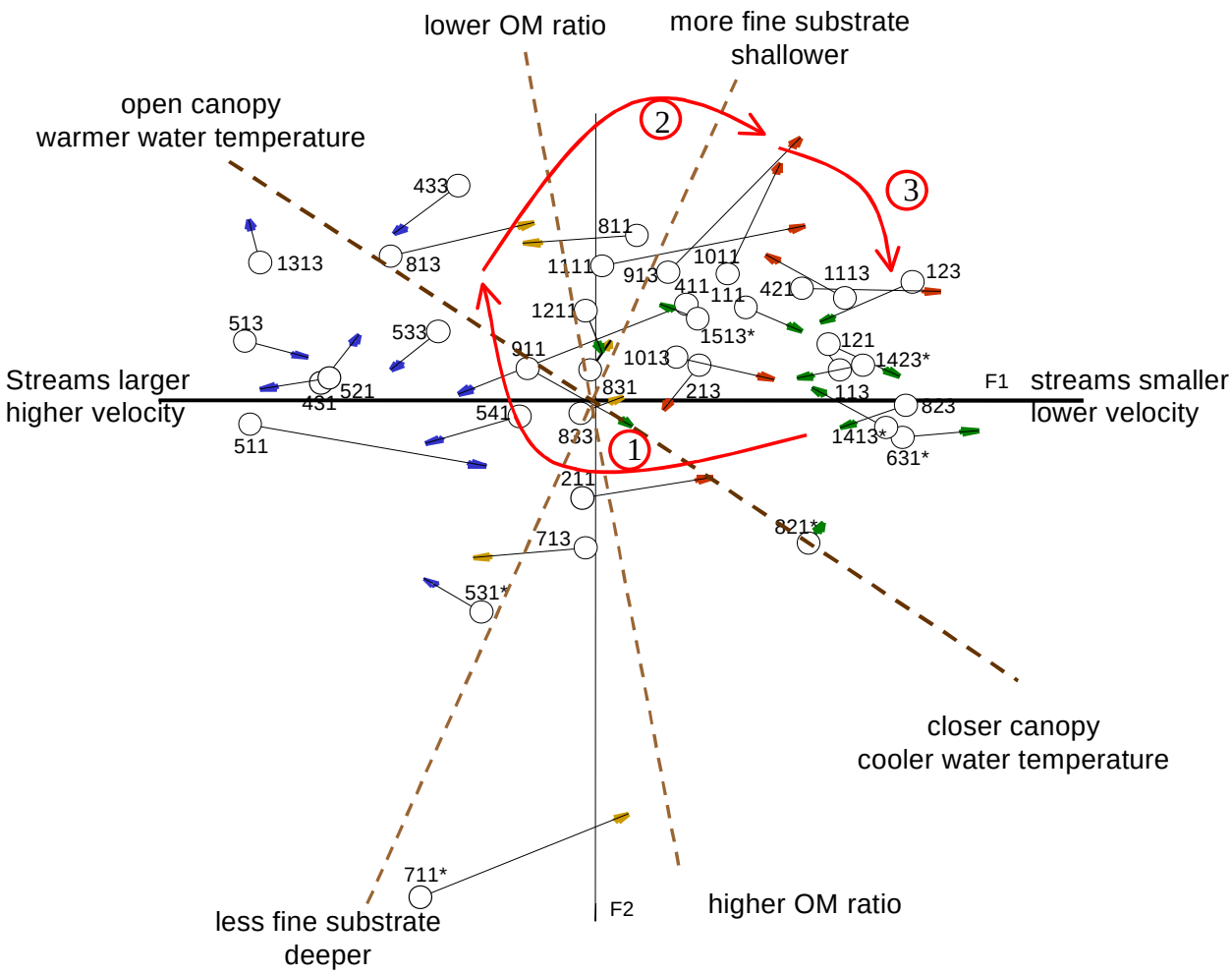

FIGURE 51. Co-inertia analysis with position of the samples due to environmental variables (circles) and due to macroinvertebrate fauna (arrow). Arrows coloured according to cluster groups: blue (streams > 6m), green (most reference samples), yellow (open streams) and red (most disturbed streams). Red arrows illustrate chronological sequence of logging activities between groups green, yellow and red.

It has to be underlined that group yellow is on the same F1 axis side as group blue (larger rivers). This let think that due to logging activities, habitat changes influencing the macroinvertebrate fauna, could lead to conditions in smaller streams that could be compared to conditions in larger streams. Consequently, we would have a shift downstream, in the longitudinal gradient, as well as in the river continuum, due to logging activities. These aspects are examined further.

The macroinvertebrate fauna had just been considered alone. The co-inertia analysis which took into account both environmental variables and macroinvertebrate fauna is examined thereafter. On figure 51, position of the samples following environmental variables (circles) and position of the samples following macroinvertebrate fauna (arrows coloured according to cluster groups) are represented. Arrow length represents the relationship between the macroinvertebrate fauna and the environmental variables used to describe the habitat: a short arrow illustrates a strong relation. Most samples belonging to green cluster have short arrows, whereas the ones belonging to red cluster have long arrows. This indicates that there is a delay (discrepancy) between the stream habitat and the macroinvertebrate composition responses to logging.

Stream size described by width and flow velocity has a strong contribution to co-inertia axis F1, from larger streams on the left to smaller one on the right. The chronological sequence following logging activities is not strictly similar to CoA (fig. 50): groups blue and yellow are still close to each other, as well as group green and red. Group green is decentred compared to figure 50, but the chronological sequence represented by the red arrows in circle remains valid.

If this sequence is considered at the view of the environmental variables, the following “evolution” could be: along arrow 1) the canopy opens up and the water temperature becomes warmer during and a few months after logging; along arrow 2) the fine substrate increases and the Organic Matter ratio decreases 1 to 3 years after logging; and along arrow 3) the system recovers within 4 to 5 years after logging, with the canopy which closes down, the water cools down and the Organic Matter ratio increases.

The samples “before” and “after” logging activities were not statistically analysed due to inadequate sampling design. In order to detect what happened before and after, a BACI or a nested design should have been applied. A BACI (repeated **B**efore and **A**fter sampling at **C**ontrol and **I**mpacted sites) design such as described by Underwood (1991) would have required each site to be sampled several times, at random, before and after the start of logging activities. The nested design (also described by Underwood, 1991) required not only samples to be taken before and after logging, but in each case, data should have been collected in two periods, in each of which the macroinvertebrates should have been sampled three times. The data thus form a nested (or hierarchical) series, with before versus after logging, periods nested randomly in each of these and times of sampling nested randomly in each period.

In conclusion:

- relationships are strong between environmental variables and macroinvertebrates composition, but disturbance due to logging weakens these relationships
- during and a few months after logging, the impact of logging leads the environmental conditions in small streams to mimic the larger streams
- small streams seem to recover from logging impacts between 4 to 5 years after logging in absence of other on-going disturbance

The natural variability in the response of the samples following logging was underlined, as well as the difficulty in separating stream size effects and disturbance due to logging activities. The dataset is compared thereafter with existing studies, such as longitudinal gradient concept, river continuum concept and disturbance theories.

8.3 The longitudinal gradient and logging activities

The unidirectional flow of river system (Hynes, 1975; Petts & Calow, 1996a) leads to a longitudinal gradient, from source to sea (see figure 3 on page 13, in "State of the Art"). Table 27 compares what was proposed by the longitudinal gradient concept and what was observed with the environmental variables in the study sites. Only the reference (unlogged) streams less than 6 meter width were compared with the larger streams (6 to 10 meters width). Logging effects on the larger streams were assumed to be negligible due to the dilution effect.

The trends observed in this study were similar to the trends proposed by the longitudinal gradient, except for substrate composition. Moreover, water temperature, conductivity, canopy opening and OM quantity were significantly different with Man-Whitney U test between both stream sizes. When substrate composition would be influenced by logging activities in larger streams, the fine substrate would increase, which was not the case. The explanation for this difference between proposed and observed trends, probably lies in the geology of the area. The study site was located in a sedimentary undulated plain, more or less homogeneous, from headwater (< 6 m corresponding to 3rd to 4th order streams) to larger downstream streams (6 to 10 m, corresponding to > 5th order stream).

TABLE 27. Predicted trend according to longitudinal gradient (Petts & Calow, 1996a) from source to sea, and trend observed with our environmental variables by comparing small streams (< 6m) with larger ones (6 to 10 m). Impact of logging activities predicted according to literature and impact observed in our study.* significant difference with Man-Whitney test (p<0.05).

	longitudinal gradient		logging activities	
Environmental variables	**predicted**	**observed**	**predicted**	**observed**
Depth	↗	↗	↘	→
Flow velocity	↗	↗	↗	→
Water temperature	↗	* ↗	↗	* ↗
Conductivity	↗	* ↗	↗	→
Canopy opening	↗	* ↗	↗	* ↗
Substrate composition:				
substrate < 6 cm	↗	→	↗	↗
substrate > 6 cm	↘	→		
Fine Organic Matter (< 1mm) quantity	↘	* ↘	↘	* ↘

In table 27, trends predicted by literature as impact of logging activities on stream and trend observed in this study are also compared.

In figure 7.1 on page 110, **hypothesis 1a)** that logging activities have reported impacts such as increasing sediment load in the rivers, which could lead to decreasing depth and increasing flow velocity was examined. This hypothesis was based on several studies which demonstrated an increase in sediment load (e.g (Brown & Krygier, 1971; Chappell et al., 1999; Douglas et al., 1992; Gurtz & Wallace, 1984; Swank et al., 2001), as well as an increase in stream discharge following canopy removal (Hewlett & Helvey, 1970; Hornbeck et al., 1970; Swank et al., 2001; Bent, 2001). Most of these studies were done under temperate climate after clearcutting of the watershed, without any riparian buffer zone along the stream system. Whereas, selective cutting system was applied in the study site. Riparian buffer zone persisted even if streams were frequently crossed. East Kalimantan lies under equatorial climate with high sensitivity to erosion. As a matter of fact, studies in Danum Valley (North of Borneo, Sabah, Malaysia) underlined this erosional matter (Douglas et al., 1992). Hypothesis 1a) **could partly be validated with the study data**: a significant increase in fine substrate (<6cm) and in fine mineral quantity (<1mm) was observed, but depth and flow velocity were not significantly different.

A transparency snellen tube was used to measure the suspended sediment, but data were not analysed, as they should have been measured on a regular basis. Conductivity, another measure, did show significant differences between reference samples and disturbed ones with Kruskal Wallis ANOVA ranks test, but differences were found significant between streams sampled in June-August 2000 and in March-May 2001. Thus difference in conductivity could not be attributed to logging or sampling seasons.

In the same chapter **hypothesis 1b)** was proposed: by harvesting trees, logging activities reduced trees density along stream sides by opening of the canopy. A potential consequence is the increase of incident light into streams, which may cause water temperature to increase. This hypothesis was based on studies where an increased insolation, caused by a decrease in riparian and catchment vegetation, caused in turn stream temperature to increase (Brown & Krygier, 1971; Collier & Bowman, in press; Rishel et al., 1982).

The 1b)-hypothesis **is partly validated** by these results, as canopy opening was higher during and 6 months after logging activities and as water temperature was significantly different and higher 1 to 3 years after logging. The canopy opening during logging activities was already lower 1 to 3 years after logging with vegetation growth, whereas higher water temperature as a result of canopy opening was observed later on, from 1 to three years after logging. Canopy opening was a rather good measure, but only reflected local conditions at the site of measurement. Water temperature better represented the whole watershed condition, but remained subject to natural fluctuations, even if temperature was rather constant in this region all through the year.

Even several years after logging (group c), d) and e)), the temperature remain higher than reference sites (a). There could be several explanations linked together. First, the seasonality could be one of theses, but the Mann-Whitney U-test on the 26 samples according to the date of sampling shows no significant difference between June-August 2000 (n=13) and March-May 2001 (n=13). Second, the secondary vegetation (after regrowth) may be of different “shading quality” due to different cover density and thus water temperature could be higher. Third, water temperature may better represent the whole upstream watershed than does the canopy opening measure at one point, meaning that the water could be warmed at different locations in the watershed. Fourth, as already mentioned, groups d) and e) seemed different, with lower depth and flow velocity, which could lead to naturally higher water temperature. Partly related to water temperature increase, an increase in autochtonous production was partially observed, but not quantified. Presence of periphyton and algae were noted and were found to be present in two cases, in larger streams and streams during logging where canopy was open.

Last **hypothesis 1c)**, a decrease in Organic Matter should be observed after logging activities due to less density or less regular input of material from the surrounding trees. Alterations in the quantity, quality, and

timing of inputs of allochtonous organic matter have been reported by Lyford and Gregory (1975), as a consequence of logging activities. This hypothesis **is validated** with these data, as fine Organic Matter quantity and ratio were lower during and after logging activities, as well as 1 to 3 years after logging, compared to reference samples.

Table 27 illustrates that trends observed with the streams followed trends proposed by the longitudinal gradient. It also illustrates that trends observed after logging activities do not match with all trends proposed by the literature. This was attributed to the fact that the chosen environmental variables were mainly used for stream habitat description, and not on a long-term monitoring basis. Another explanation is the time frame considered, which differed from one study to the other.

Most trends proposed by longitudinal gradient and by logging activities, from literature, were similar except for depth. This highlights that precaution is needed when comparing streams (size has to be as much similar as possible) in situation of logging activities and that distinguishing both effects (size and logging) remains difficult.

In conclusion,

- trends observed with environmental variables from this study, from smaller to larger streams are similar to trends proposed by the longitudinal gradient concept
- trends observed in the study site after logging activities do no match all trends proposed by the literature

8.4 Macroinvertebrate fauna

8.4.1 Density and richness

Macroinvertebrate densities observed in the study site remained low compared with other densities of macroinvertebrates recorded in tropical or equatorial regions of the world (Table 28).

TABLE 28. **Macroinvertebrate densities (individual/m²) in several countries or region of the world.**

Countries or region	densities / m^2	References
Borneo, East Kalimantan	**180 - 2'130**	**this study**
Big Sulphur Creek, California	6'800-56'000	McElravy et al., 1989
England, Cow Green	1'000-12'000	Armitage, 1978
Germany	6'000 - 50'000	Illies, 1971; Ringe, 1974
Hong Kong	2408-6416	Dudgeon, 1988
Kenya	2'000 - 10'000	Dobson et al., 2002
Papua New Guinea	5'000 - 13'000	Yule, 1996a
South Africa	300 - 1'600	King, 1983
USA, Virginia	7'800-8'600	Leonard et al. 1985
Zaire	14'630	Böttger, 1975

Dobson et al. (2002) compared density of macroinvertebrates (number of individual per square meter) from 3 Kenyan sites with one site in South-west France, 2 sites in south-east and 2 sites in north-east England. He found that densities were significantly higher in Kenyan streams (range 2'000-10'000) than in European streams (range 1'000-5'000), although highest densities for most Europeans sites were within the range recorded from Kenyan sites.

The data from this study revealed a high **number of taxa**, with at least 115 taxa identified mostly at family level in a region covering only 85 km². The number of family is approximately 70. As the macroinvertebrate were not identified at the same taxonomic level, it was difficult to provide comparison from other countries. But table 29 proposes some numbers of Ephemeroptera genera in order to compare with the 43 genera found in the study. Regions of the world cited in this table cover large areas, which were taken into account to underline the richness of the study site.

TABLE 29. Number of Ephemeroptera genera in some regions.

Countries	Number of Ephemeroptera genera	References
Borneo, East Kalimantan	**43**	**this study, 85 km²**
Northeast Asia (Japan, Korea, FE Russia NE China)	47	Bae, 2001
North America	85	McCafferty, 2001
South America	91	Pescador et al., 2001
Switzerland	27	Landolt & Sartori, 2001

Shannon indices and alpha log series were high, dominance was low and evenness was high in general, whatever stream size was considered. But richness and diversity was higher in the larger streams, which reflected the greater diversity of micro habitat encountered in lower reach, compared to upstream (Dudgeon, 1999). Based on the deciduous forest river system used to derive the River Continuum Concept (Vannote et al.,1980), biodiversity should exhibit a unimodal pattern (Vannote & Sweeney, 1980; Ward, 1998) with maximum values in the middle reaches (stream order 4 or 5).

8.4.2 Why such a low density and high richness?

Seasonality affects the macroinvertebrate density and life cycle under temperate climate. But, in the study site, according to the available data from Malinau rainfall station, most of the months received more than 200 mm rain in average and thus could be considered aseasonal. Dudgeon (1999) studies showed that (for a variety of reasons) there might be interstream variation with respect to seasonal fluctuations in zoobenthos such that either the wet or the dry season might be the period of greater abundance. In Big Sulphur Creek (northern California), McElravy et al. (1989) studied during seven years macroinvertebrates by sampling them twice a year (Mid-May and late August). They noticed that the density in macroinvertebrates reflected the variability in precipitation.

In order to get an idea of seasonality in the study region, several temporal scales should have been considered: several time during one year, several years and during El Niño wet and dry 4.5 to 5.5 years interval (Chappell et al., 2001). This could not be done within the allocated thesis time frame. The last recorded El Niño dry period was in 1997-98 and thus this study was not affected by this phenomenon.

It was difficult to clearly identify the wet and dry seasons in the study site, as illustrated in figure 10 on page 31 ("Study site"). With the two sampling seasons at 8 months interval time, it was not possible to cover any year-to-year variability and the possibility that these sample periods were particular cannot be

excluded. If samples in streams < 6 meters are compared, mean density for June-August 2000 was 525±305 (n=13) and for March-May 2001: 730±315 (n=13). The difference was not significant between the two sampling seasons. The higher density recorded in mean value for 2001 was probably due to more samples 6 months after logging where density has proven to be higher. In most samples and in both sampling seasons, a range of larvae at different maturity stage were collected, very young larvae to mature one, which let think that seasonality in the emergence of the adults was not marked.

Flooding and spates. Large increases in discharge, the most frequent cause of stream disturbance (Resh et al., 1988), had been shown to be catastrophic for most stream benthic communities. Even relatively minor spates can result in reduced macro benthic densities, presumably because of increased drift rates and mortality from increased bed load movements (Brooker & Hemsworth, 1978; Sagar, 1986). Taxa attached to or situated between stones that are subject to displacement may be more susceptible to spates than free-living and mobile species (Thorup, 1970).

During field work, it was observed several times that streams were reacting very quickly to rain. During rainy events, less than fifteen minutes after the beginning of precipitation, water level was rising. The macroinvertebrate fauna must be adapted to these frequent events (every two or three days). Lelek (1985) qualified these extremely high and frequent fluctuations of water level he observed during his study as probably the most decisive ecological feature of stream system in the upper basin of Rajang (North Borneo). Rivers in Papua New Guinea were also characterised by extreme short-term variability in flow (Yule & Pearson, 1996). However, this situation did not influence macroinvertebrate densities observed in their study.

Despite the sometimes catastrophic effects of floods, macroinvertebrate community recovery can be very rapid, resulting in a community structure similar to that preceding the disturbance. The presence of a range of refugia, each likely to be used by different sets of species, must be largely responsible for this resilience (Townsend et al., 1997). Local refugia that may be exploited by benthic invertebrates include large stable substratum particles, holes, interstices and pieces of debris that offer protection from disturbance (Lake, 2000), dead zones, where shear stresses on the bed are always low, even at high discharge (Lancaster, 1999), and the hyporheic zone (Palmer et al., 1992). In this study, it was observed that two taxa (*Platybaetis probus* and *Atopopus* sp) behaved in a particular way: they climbed on emergent large boulders near the flow surface and remained in this upper layer for hours. This might be a strategy to escape during spates. The hyporheic zone sounds another good refugia in the stream of this study: it was observed that many individuals collected during the study were of small body size. This in comparison to temperate fauna. This small size might be an adaptation to escape during frequent spates by dwelling in the hyporheic zone.

The high diversity found was part of the spates and flooding shaping mechanisms. The Intermediate Disturbance Hypothesis (IDH; (Connell, 1978) could explain the high richness and diversity observed in our study. Non-equilibrium theories of community structure invoked disturbance as a major contributor to the maintenance of biodiversity on ecological time scales (Stanford & Ward, 1983; Townsend & Scarsbrook, 1997; Ward, 1989).

In conclusion,

- spates and flooding are probably the driven events which could best explain the high diversity and low density of the macroinvertebrates observed in this study, this in accordance with the Intermediate Disturbance Hypothesis.

8.4.3 Effect of logging activities on macroinvertebrate density, richness and diversity

According to Gurtz & Wallace (1984), clear-cutting of a watershed is a large-scale, low frequency, anthropogenic disturbance that has no precise natural analog with respect to its effects on a stream ecosystem. Many concepts relating to disturbance therefore cannot be applied to such studies; biota have not evolved appropriate adaptations to such disturbance. Death (2002) studied the relationships between macroinvertebrates and substrate disturbance, but he did not found statistical evidence for a unimodal relationship as predicted by IDH.

An increase in macroinvertebrate density had been observed in several studies, as a result of disturbances. For example, Noel et al. (1986) studied the effects of forest clearcutting in New England on macroinvertebrates in a two and three years old clear cut watersheds. The macroinvertebrate density in cut over streams was 2-4 times greater than in the reference streams, but the number of taxa collected was similar in both cut over and referenced streams. Differences in macroinvertebrate densities found in Noel study were of the same magnitude as those found by Erman & Erman (1984) and Newbold et al. (1980) in northern California. On the other hand, several studies reported a general decrease in macroinvertebrates density with increasing amount of sediment (Lenat et al., 1981; Peckarsky, 1985; Bourassa & Morin, 1995).

Both an increase and a decrease in macroinvertebrates were observed in this study, this depending on the time after logging. The increase in macroinvertebrate density did not reach the extend of above mentioned studies. The mean density in reference samples was approximately 600 individuals per m^2 and reached 900 during logging and the few month afterward. Density was already lower 1 to 3 years after logging which had not been reported in the above mentioned studies. One explanation for this increase in macroinvertebrates might be that the increasing light due to canopy opening because of logging activities, might promote the periphyton growth, which in turn offered more feeding capacity for grazers-scrapers macroinvertebrates. A significantly higher density of this feeding group was observed in the study. Another reason might be the decrease in sensitive taxa, leaving more space for resilient taxa to develop, which led to an overall increase in density, accompanied by a decrease in richness. Lower density after logging could be attributed mainly to fine sediment increase and to lower available Organic Matter quantity.

Death (2002) observed that the **number of invertebrate species declines** as substrate disturbance increased in forest streams. Studies examining the response of taxa richness to deposited sediment reported the elimination of taxa with increasing deposited sediment (Lemly, 1982), or no response to increasing fine sediment over the range of 0 to 30% in an Appalachian USA stream (Angradi, 1999).

In this study, the number of taxa after rarefaction was similar during logging activities and a few months afterwards compared to reference sample, but this number was lower 1 to 3 years after logging.

The main explanation for species (or taxa) decline and changes in density may lie in higher amount of sediment following logging activities with resulting consequences, such as:

- increasing substrate embeddedness and altering substrate particle-size distribution (Culp et al., 1983; Erman & Erman, 1984) producing a reduction in habitat quantity and quality. Deposited sediment affects the structure and function of benthic macroinvertebrate communities
- clogging of the hyporheic zone (interstitial spaces in streambed, (Schälchli, 1992). This clogging reduces both living space for groundwater animals and the exchange rates leading to poorly oxygenated interstitial waters. In undisturbed situation, hyporheic zone are highly interactive with contiguous surface water.

In Death (2002), the two evenness measures used (Berger-Parker and Simpson's indices) indicated that macroinvertebrates communities became increasingly dominated by a single taxon as disturbance level increases. Experimental studies (e.g. Robinson & Rushforth, 1987; Death, 1996a) had also found that increased levels of disturbance reduced both invertebrate diversity and periphyton abundance. Whether diversity declined because of physical stress (direct physical removal) or low food levels (abrasion of stone surface biofilm) was rarely clear. According to Minshall (1984), benthic invertebrates are excellent candidates for monitoring sediment conditions in streams because substrate is believed to be the most important factor regulating invertebrate distribution and abundance at the local or reach scale.

In conclusion,

- macroinvertebrate density, richness and diversity are not only good indicators of logging activities, but also of the time after logging

8.5 The River Continuum Concept and logging activities

Such as longitudinal gradient describing environmental variables from source to sea, the river continuum concept from Vannote et al. (1980) made predictions about downstream changes in functional feeding groups (for details, see figure 2 on page 12, chapter "State of the Art").

Figure 52 presents an adaptation of the River Continuum Concept to the streams of this study site. We proposed to name this adaptation as the "Tropical Stream Concept". This Tropical Stream Concept has to be considered as an hypothesis which has not been tested and will need further investigations to be supported. The figure juxtaposes trends for the functional feeding groups proposed by the river continuum concept in temperate climate, from headwater rivers to downstream, with trends observed for the streams in this tropical study site. To facilitate comparison and discussion, the effects of logging are also included. Table 30 describes these trends in a different way. The discussion, thereafter, refers to figure 52 and table 30.

- "The **predators** component changes little in relative dominance with stream order" (Vannote et al., 1980). The same trend was observed in this study. Gurtz and Wallace (1984) found that predators apparently responded to changes in abundances of other groups, during and immediately after logging activities. This was not observed in this study, even if densities of certain groups (e.g. grazers-scrapers) increased.
- **"Grazers-scrapers**, in low proportion in headwater rivers should increase downstream (rivers 10 meters width)" (Vannote et al., 1980). The exclusion of light by riparian vegetation restricts in-stream primary production and consequently also limits the peryphiton-grazing scrapers (Cummins et al., 1995). This increasing trend in grazers-scrapers was also observed in our samples.
- "A high proportion of **shredders** which quickly decrease downstream" (Vannote et al., 1980): a very low proportion of shredders was recorded in the study site. This shredders paucity had been mentioned in several studies in Southeast Asia, Hong Kong, New Guinea (Dudgeon et al., 1994; Dudgeon, 1999; Yule, 1996b), in New Zealand and Australian streams (e.g. Winterbourn et al., 1981; Marchant et al., 1985), Central America (Pringle & Ramirez, 1998) and in Kenya (Dobson et al., 2002).

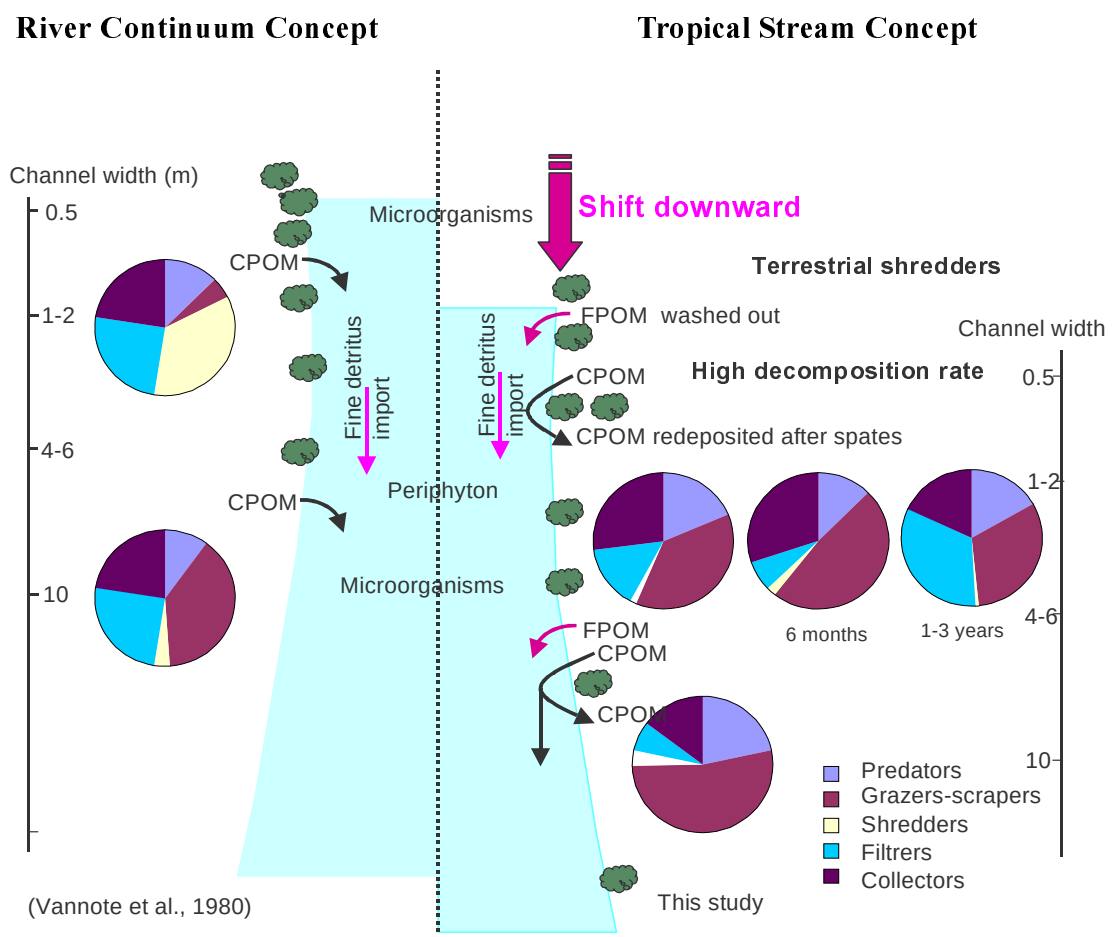

FIGURE 52. Comparison between the River Continuum Concept (Vannote, 1980) with the Tropical Stream Concept developed from our study site. FPOM = Fine Particulate Organic Matter; CPOM = Coarse Particulate Organic Matter.

TABLE 30. Summary of trends proposed in the River Continuum concept, the Tropical Stream Concept observed in our study site and the impact of logging activities. Geometric polygons illustrate the decrease and increase in proportion of the feeding groups. Arrows indicate the downstream shift.

	Predator	Grazer-scraper	Shredder	filter	collector
River Continuum Concept, from source to sea					
Tropical Stream Concept, from < 6m to 6-10m					
Impact of logging activities, from undisturbed to recently logged to 1-3 years after logging					

Dudgeon (1999) summarised some possible explanations, such as “an increased importance of mycoflora in litter breakdown in tropical streams” and/or “a higher investment in phytochemical defence by tropical leaves making them unpalatable to shredders” and/or “trophic flexibility and hence functional feeding group misclassification”. For example, Leptoceridae (Trichoptera) belongs to Collector-Scraper according to Dudgeon (1999) and to Shredders according to Dobson et al. (2002). Another explanation that could be applied to the study site is:

- “a lack of shredders could reflect limited stream retentiveness for leaf litter” (Dudgeon, 1999). This hypothesis is attractive at the light of the field observations: spates during and after rainy events revealed that leaf litter (part of CPOM indicated by red arrow in figure 52) were quickly transported downstream and deposited high away from the water level. As these flashy rainy events occurred every 2 or 3 days, it was supposed that leaf litter did not remain long enough into the water to be efficiently decomposed by shredders. Whereas, in the larger streams (>6m) and in the unique 30-meter width river, more shredders were observed, maybe due to more available pools that act as deposit place for leaf litter which might support more shredders.

- “As the litter is converted to finer organic particles (FPOM), it supports population of **collectors and filters** which increase downstream” (Vannote et al., 1980). FPOM input (green arrow on fig. 52) directly from watershed drainage during rainy events is suspected to be higher than under temperate climate. Litter decomposition by terrestrial insects (shredders) and microorganisms, due to higher temperature and humidity may be more quickly converted into FPOM. After washing out by the rain, this FPOM end up in the stream and may be directly available for collectors and filters. In that case there should be more amount of FPOM in smaller streams then in larger ones. As a matter of fact, OM quantity and OM ratio measured in this study are higher in smaller streams compared to larger streams.

  This FPOM quantity and ratio was also found to be lower during and 6 months after logging activities and at lowest 1 to 3 years after logging. This is probably due to several reasons, such as: a) FPOM decreased in quantity due to the decrease in litter and in leaves input following the removal of trees by logging; b) FPOM deposited on the stream bottom could be trapped by the increasing amount of sediment, becoming less available for the gatherer. But on the other hand, the FPOM input may be available for the filters when it remained into the water column, before deposition on the bottom where it could be trapped and periodically released in suspension during rainy event. This could make FPOM more available for filters than for collectors. This argument could be supported by the ratio filters to collectors: reference streams: 0.5; during and 6 months after logging: 0.3; 1 to 3 years after logging: 4.

Omnivores are not represented in figure 52 as they were not considered in the RCC concept. But they were similar in smaller streams (16%) compared to larger streams (15%). Omnivores not only contained “true” omnivorous, but as well mixed functional feeding groups, such as filter-predators, shredder-predators and shredder-scrapers. Their proportion remained similar during and 6 months after logging but was higher 1 to 3 years after logging (27%), this compared to reference samples. This could be explained by their wider feeding range. Generalists have better adaptive abilities than specialists.

To summarise, in order to be able to compare feeding groups proposed in temperate climate by the River Continuum Concept with feeding groups observed in our study, a downstream shift is needed. The streams < 6m from this study are to be compared with larger temperate streams (10m or more). This, because of the “earlier introduction” in the system of FPOM directly from the watershed. Even with this downstream shift, the RCC prediction is only partly observed with the functional feeding groups from this study: for predator and grazers-scrapers, but not for detritivorous (shredders, collectors and filters). But the paradox appears when the general trend is considered, from allochtonous input in headwater which should be dom-

inant compared to autochtonous input which should become dominant downstream: 36% of allochtonous consumers (detritivorous) were observed in the smaller reference streams and 24% in the larger ones; 27% of autochtonous consumers (grazers-scrapers) were observed in the smaller reference streams and 44% in larger ones.

Once again, effects due to logging activities are similar to effects due to the shift downstream. During logging activities, most feeding groups acted as if they were in condition of larger streams. But one to three years after logging, functional organisation seemed to be disorganised: predators remained similar as during and 6 months after logging; grazers-scrapers density was lower and had lower proportion than reference samples, but recovered to one extent due to vegetation growth. Omnivorous had higher proportion compared to during and 6 months after logging and compared to reference samples. They are probably the more adapted to new environmental conditions as generalists. Shredders had the lowest density and proportion compared to reference site; filter density was higher and collector density lower to reach same proportion as it would be in larger streams.

It can be noticed that feeding organisation 1 to 3 years after logging in this tropical studied streams is close to the one observed in the River Continuum concept for a 10 meter width stream. Could that mean that the RCC concept was not developed from such a pristine stream ecosystem as expected?

In conclusion,

- a Tropical Stream Concept is proposed for the feeding groups of this study in a tropical environment, which partly corresponds to a downwards shift in the River Continuum Concept from Vannote et al. (1980).
- Tropical Stream Concept is based on the hypothesis that higher organic matter decomposition rate and terrestrial shredders provide the FPOM directly available for aquatic macroinvertebrates in the headwater catchment

8.6 Indicator taxa

In chapter “Faunistical composition of cluster groups” on page 94, the contribution of the taxa to each cluster group was calculated. Some taxa were present in one cluster group only and some taxa were absent from one cluster group only (table 31). Most taxa which were only present in one cluster group were also taxa found in few number and in few sampling sites. 18 taxa belonged to this description, both by their total number collected (less than 3 individuals) and by the number of location (2 locations only): Libellulidae, Macromiidae, Georissidae, Empididae, Psychodidae, Stratiomyidae, *Liebebiella*, *Brachycercus*, Ephemerellidae genus 1, *Asionurus*, *Nothacanthurus*, *Choroterpes*, *Genus 11* (Leptophlebiidae), *Euthraulus*, *Prosopistoma*, Amphypterygidae, Calopterygidae and Lestidae.

These taxa can characterise the group they belong to, but cannot be used as indicator taxa alone, because of their low number. It would never be sure not to find them because they disappeared due to a difference in stream size, or due to the level of disturbance, or because they were just missed /skipped. Whereas, taxa which are absent from one group can be more indicative. For example, if several Lepidoptera are found in a sample, it can be guessed that this sample may not belong to group green and that it may be disturbed by logging activities.

TABLE 31. Taxa present only in and taxa absent only from one of the cluster groups blue (streams > 6m), green (most reference samples), yellow (open streams) and red (most disturbed samples). *taxa in low abundance.

	Blue	Green	Yellow	Red
Taxa present		Brachyura		
	Baetidae *genus 5*	*Psychodidae	*Libellulidae	
	**Prosopistoma*	*Atopopus*	*Macromiidae	*Empididae
	**Teloganella*	*Leptophlebiidae *Genus 11*	*Georissidae	**Liebebiella*
	Hydropsychinae 4	*Lestidae	**Brachycercus*	**Choroterpes*
	Hydropsychinae 7	**Euthraulus*	**Nothacanthurus*	*Aphipterygidae
Taxa absent	*Isca*	Lepidoptera	Dytiscidae	Lampyridae
	Diplectroninae	Hydroptilidae	Macrobrachium	Baetidae *genus 4*
	Polycentropodidae		Baetidae *genus 7*	*Platybaetis*
			Pseudocentroptiloides	*Platybaetis probus*
			Caenidae *Genus 9*	*Caenodes*
			Gerridae	*Potamanthus*
				Glossossomatidae
				Ecnomidae
				Macronematidae

The presence or absence of a taxa can be an indication, but is not enough to characterise samples. The abundance of the taxa should also be considered. Therefore, for each faunistical cluster groups, the taxa contribution calculated in "Faunistical composition of cluster groups" on page 94 was used. Table 32 groups the taxa which presented similar pattern behaviour. This pattern is illustrated in figure 53.

"open canopy" taxa, indicates the taxa which contributed to both group blue (larger rivers) and to group yellow (during logging activities, when canopy opening was high). These taxa were in low abundance or absent from group green and red. Their presence in group yellow seemed to mimic larger stream habitat;

"sensitive" taxa records taxa which responded as soon as disturbance started, by a lower density during and after logging (at least until 3 years after logging). Their density is higher in group with reference sites. Plecoptera are usually considered as sensitive taxa, such as in temperate climate (IBGN index).

"**pulse" taxa**, describes taxa which were higher in density during logging and 6 months after, but were lower 1 to 3 years after logging. It is often assumed that Chironomidae are tolerant to, or even prefer, degraded habitat, which is reflected in a suite of ratio metrics incorporating Chironomidae (see Rosenberg & Resh, 1993). Zweig & Rabeni (2001) found that Chironomidae richness and density were not correlated with deposited sediment, with one exception, whereas Angradi (1999) found that, with an increasing percentage of fine sediment, Chironominae density and percentage Chironominae declined but percentage Orthocladinae increased. This probably because the subfamily Chironominae comprises most of the filter feeders in the family Chironomidae (Wallace & Merritt, 1980), and sediment is known to interfere with filter feeding. Chironomidae in this study were identified at family level only. It is suspected that during logging activities, sediment size are coarse and becomes finer after logging, interfering with filter feeding at that stage.

Caenis received the tolerance value for Deposited Sediment Biotic Index (DSBI) of 1 (=intolerant) by Zweig & Rabeni (2001) in their study of biomonitoring deposited sediment using benthic invertebrates. But both Zweig & Rabeni (2001) and Angradi (1999) found a lack of relation between any biotic index and deposited sediment measures. They suggested that the commonly used BI (modified Biotic Index, Hilsenhoff, 1987) is fairly insensitive to habitat alterations caused by deposited sediment.

TABLE 32. taxa grouped by similar pattern behaviour.

"open canopy" taxa	"sensitive taxa"	"pulse" taxa	"recovery" taxa	"adaptive" taxa
Platybaetis	Scirtidae	Psephenidae	*Labiobaetis*	Diplectroninae
Lepidoptera	Elmidae	Chironomidae	*Cynigmina*	Simuliidae
Hydropsychinae 5	Athericidae	*Jubabaetis*	Helicopsychidae	*Isca*
	Limonidae	Baetidae *Genus 3*	Hydropsychinae 1	
	Caenodes	Baetidae *Genus 4*	Hydropsychinae 2	
	Caenidae *Genus 8*	*Platybaetis*	Platystictidae	
	Euthraulus	*Caenis*		
	Habrophlebiodes	*Hyrtanella*		
	Polyplocia	Teloganodidae *Genus 12*		
	Potamanthus	*Teloganodes*		
	Helotrephidae	Megaloptera		
	Perlidae	Glossossomatidae		
	Leptoceridae	Hydropsychinae 3		
	Philopotamidae	Xyphocentronidae		
	Polycentropodidae	Euphaeidae		
	Tricladia			

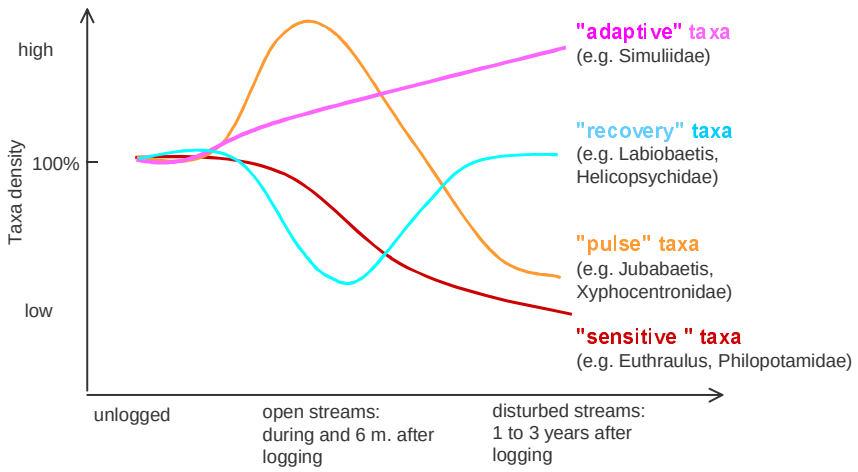

FIGURE 53. Indicator taxa grouped by categories according to their pattern.

Gurtz & Wallace (1984) found an increase in *Baetis* spp. and *Ephemerella* spp. as a response to logging. They considered them as collector-gatherers according to (Merritt & Cummins, 1978). *Baetis* spp. was not

found in the samples, but *Jubabaetis*, *Genus 3* (Baetidae) and *Platybaetis* will be judged as equivalent. They were considered as scrapers according to Dudgeon (1999). They were all in higher density during logging and 6 months after: *Jubabaetis* density averaged 17.5 x higher than that of reference samples; *Genus 3* (Baetidae) 12.6 x higher and *Platybaetis* 5.5 x higher. Wallace & Gurtz (1986)calculated for *Baetis* spp., an increase of 17.6 x higher in average in the stream draining the clear-cut catchment than that of the reference stream. *Ephemerella* spp. were not found as well in the samples, but the two Ephemerellidae genera, *Hyrtanella* (15x higher) and *Uracanthella* (5 x higher) had similar trend. *Uracanthella* is not listed in the "pulse" taxa, being less abundant than *Hyrtanella*. They were considered as collector-shredder according to Dudgeon (1999).

Gurtz and Wallace (1984) also mentioned that the increase in these mayfly genera, *Baetis* spp. and *Ephemerella* spp. was a nearly universal response in streams following logging, whether in the Oregon Cascades (Hawkins et al., 1982), in northern California (Newbold et al., 1980; Noel et al., 1986), or in the southern Appalachians (Woodall & Wallace, 1972; Haefner & Wallace, 1981). These generalist feeders typically have short generation times and high fecundity (r-strategist).

"recovery" taxa, describes taxa which were lower in density during and 6 months after logging, compared to reference samples, acting as "sensitive" taxa in the first step, but were higher in density afterwards (1 to 3 years after logging) to come back (4 to 5 years after logging) to the same or even higher density compared to reference samples.

"adaptive" taxa, describes taxa which were in higher density during and after logging (even 1 to 3 years after) compared to reference samples.

In conclusion,

- several indicator taxa are identified, corresponding to different conditions, unlogged versus logged and to different time interval after logging, from recently logged until 4 to 5 years after logging.

CHAPTER 9

Outcome, limitation and further research

The main objectives of this thesis was to study the effects of logging activities on ecological water quality in a tropical forest. Logging activities were assessed at landscape and habitat scales. Ecological water quality were assessed at local scale as indicator of biodiversity, an essential element of sustainable forest management. The evaluation of the effects of logging activities on the streams environmental variables and on the benthic macroinvertebrates contributed to evaluate the forest quality.

At landscape scale, satellite images enabled to inscribe the concession area (480 km^2) containing the study site (85 km^2) within a global frame. The intensification of logging activities (quantified by the total length of the logging roads) inside the studied concession and inside the neighbouring concessions through the time, from 1991 to 2001 was clearly demonstrated. But this could not be used to assess the effects of logging on the forest quality, through vegetation classification, mostly because of vegetation homogeneity. It was highlighted that most remote-sensing tools have been developed for temperate climate or contrasted landscape features (e. g. urban versus natural, forested vegetation versus savanna). Therefore, the existing vegetation classification and indices did not suit this tropical homogeneous forested land. Moreover, as the study region was harvested for the first time by selective cutting system, the landscape fragmentation was on process, but could not be assessed yet. However, new tools are developing and are promising for the future (e.g. neural network).

It was proposed to conduct this study at two different scales, landscape and habitat. The interaction and the transfer of information from one scale to the other was not feasible. Aerial photographs would probably be the appropriate scale to work with, but were not available and the existing maps were poor and inaccurate. There is an urgent need for East Kalimantan province to acquire these information within the present context of decentralisation. This in order to plan their own future land-uses management. In that process, remote-sensing will help in developing mapping tools for this region, difficult to access and to assess in the ground. It will constitute in the

future a necessary tool not only for forest manager, but also for the new regional government.

To work in a remote and mostly undisturbed tropical forest and river system constituted a unique opportunity. Most of the river system of the world are in one way or in another impacted by human activities. In that sense, macroinvertebrates collected during the study constitutes a unique collection from natural undisturbed streams. The chapter 2, “State of the Art” underlined how little was known on the aquatic ecosystems of this part of the world. Comparison of the number and identified Ephemeroptera genera previously known (35 for whole Borneo island, at the end of the 20th century) and of the number collected during the study highlighted this lack of information. The 12 undescribed Ephemeroptera genera out of 43 gave an idea of the potential for new species to be described. The fact that they were collected from 85 km^2 area is promising for the discovery of other taxa, considering the different habitats that remains to be explored in East Kalimantan.

The effects of logging activities on the stream systems, the environmental variables and the macroinvertebrate fauna, were assessed. Due to relogging activities which occurred during the 8 months time interval between the two field seasons, the original sampling strategy could not be followed. As a result, statistical analysis applied to the datasets remained descriptive and were not as robust as expected. The chronological sequence partly disappeared and could not be fully explored. Sampling sites “before” and “after” logging could not be statistically analysed. However, results obtained with multivariate and cluster analyses indicated that logging activities do have an impact on the stream system. Based on these results, further research questions can be proposed:

- what happen when relogging activities occur in a site logged 4 to 5 years ago, or latter on? Results obtained from the 2 sampling sites 5 years after logging which experimented this relogging activities only suggested that the impacts due to relogging could be enhanced.
- environmental variables, macroinvertebrate taxa composition and functional feeding groups expressed, because of logging activities, a shift from smaller streams to larger streams, by mimic of the latter condition (canopy open, water temperature warmer, fine substrate higher,..). Does this shift be diluted or reverberate further downstream? What happen at the scale of a whole logged watershed of several hundred square kilometers?

A high richness and low density of macroinvertebrates were observed. The proposed explanation laid on a natural long-term evolution process (30 million years) which allowed a high diversity of the fauna to evolve through a probable repeated spates/flooding regime. This long-term evolution process can be applied to the forest diversity and thus diversity of the aquatic fauna can be linked to forest diversity. This underlines that ecosystems are intimately related to each other and the difficulty of taking into account each aspect and their possible implications on the others. These extremely high and frequent fluctuations of water level may also explain the low macroinvertebrate density. This high macroinvertebrate richness and low density open several questions:

- what are the strategies to escape these frequent spates? The small body size was proposed, as well as the particular behaviour of two Ephemeroptera genera (*Platybaetis probus* and *Atopopus* sp. which climbed on the rocks to be near the surface). These strategies have to be tested. And how they may explain this low density and/or high richness?
- do the soil properties of this area (water saturation and quick response to rain) influence the hyporheic zone and how this could influence the macroinvertebrate fauna?

Functional feeding groups organisation also brings some new insights. The River Continuum Concept (RCC) developed in temperate climate could only partly be applied to this study in tropical climate. Therefore, a Tropical Stream Concept was proposed, which takes into account the Fine Particulate Organic Matter as allochtonous input in the headwater catchment, directly from the washing out due to frequent and

heavy rainy events. This FPOM results from higher decomposition rate and from terrestrial shredders. It becomes now an evidence that paucity of shredders encountered in this study confirmed other finding and could be considered as a feature of this tropical stream system. Further research could be:

- to verify this Tropical Stream Concept in other tropical headwater streams and to study the implication of this concept further downstream, in the rivers (stream order >6). Further researches need to be undertaken in streams larger than the sampled ones in order to add information on the river system of this area and in order to verify and complete the Tropical Stream Concept in other regions.
- to study the relationship between the aquatic insects and the fishes. Numerous studies have been conducted on this topic under temperate climate (mainly for trouts and salmons). The Ephemeroptera are dominant in proportion in the study site and it would be interesting to study their position in the aquatic foodweb. Fishes are part of the livelihood of local population in this area. To a broader extend, it is not well known what role these headwater streams play in the reproduction of species like crabs, shrimps, fishes which are important food resources for downstream population too.

Ecological water quality indicators fulfilled the proposed objective. An indicator is considered as good when the following criteria are met: measurable, reproducible, feasible, interpretable and cost-effective. The methods used in this study to collect benthic macroinvertebrates are well-known, broadly used and established. Material used was of low cost and all softwares used for data analyses and for interpretation are available on the internet. Macroinvertebrates exhibited high diversity but low abundance, and despite the unknown fauna of this area, identification was relatively easy to generate information. They also had high lifeform diversity, restricted mobility and short lifecycle, all which made them responding to environmental changes. In summary, they constituted excellent indicators, which were successfully used in this study in tropical climate to record changes due to logging activities.

Further research questions and topics were proposed above to contribute to better understand processes occurring in tropical streams of this region. But, the main interest of this study is to be the starting point for developping benthic macroinvertebrates as a tool to contribute to management decision for sustainable use of forest. This study identified several indicator taxa which should, in a first step, be verified in other locations (in tropical Asia) and situation (logging, but as well other human impacts). This should allow, in a second step to present a simplified identification key for these indicator taxa, as well as calculation of a simple biotic index to assess the ecological water quality. With a minimum of training and experience, many people without a strong scientific background could use benthic macroinvertebrates as a tool for water quality assessment.

This tool should be mainly used by the local population as well as regional government to monitor their water quality. They are the one directly concerned (drinking water, fishing, bathing,..). Main objective for forest manager should remain to improve their logging operations, by following good practices guidelines, such as RIL (Reduced Impact Logging). The last 30 years of forestry research provides these scientific and practical knowledge. Watershed management, soil and stream protection are part of these guidelines. Despite the efficient, cost-effective and broad advantages of these good practices, especially in tropical region where erosion is high, the major problem remains the incentives to encourage the forest managers to follow these guidelines. Water quality could become one incentive for forest manager, used as a control tool by local population with the support of the regional government. Water quality becomes to be the major resource problem of our century and solutions for its management, such as monitoring its quality, need to be quickly implemented.

Bibliography

Achard, F., Eva, H. D., Stibig, H.-J., Mayaux P., Gallego, J., Richards, T. & Malingreau, J.-P. 2002. Determination of deforestation rates of the Worl's humid Tropical forests. *Science*, **297**, 999-1002.

AFNOR. 1992. Essais des eaux - Détermination de l'Indice Biologique Global Normalisé (IBGN). Norme Homologuée NF T90-35.

Allan, D. & Johnson, L. B. 1997. Catchment-scale analysis of aquatic ecosystems. *Freshwater Biology*, **37,** 107-111.

Allan, J. D., Erickson, D. L. & Fay, J. 1997. The Influence of Catchment Land-Use on Stream Integrity Across Multiple Spatial Scales. *Freshwater Biology*, **37,** 149-161.

AMDAL. 1997. Analisis dompak lingkungan hak pengusahaan hutan. Pt Inhutani II sei Malinau. Di Kabupaten Dati II. Bulungan, propinsi dati I Kalimantan Timur. Jakarta.

Angradi, T. R. 1999. Fine sediment and macroinvertebrate assemblages in Appalachian streams: a field experiment with biomonitoring applications. *Journal of the North American Benthological Society*, **18,** 49-66.

Anonymous. 1975 b. *Soil taxonomy. A basic system of soil classification for making and interpreting soil survey.* U.S. Dept. of Agric.

Anonymous. 1982. Geological mapping and mineral exploration in North-East Kalimantan (1979-1982). France: Rapport du Bureau de recherches géologiques et minières.

Armitage, P. D. 1978. Downstream changes in the composition, numbers and biomass of bottom fauna in the tees below Cow Green reservoir and in an unregulated tributary Maize Beck, in the firest five years after impoundment. *Hydrobiologia*, **58,** 145-156.

ATO/ITTO. 2003. ATO/ITTO principles, criteria and indicators for the sustainable management of African natural tropical forests. ITTO.

Bae, Y. J. 2001. Status of the knowledge of Ephemeroptera in NorthEast Asia and guidelines for future research. In: *Trends in research in Ephemeroptera & Plecoptera* (Ed. by Dominguez, E.), pp 3-6. *IX International Conference on Ephemeroptera and XIII International Symposium on Plecoptera*,Tucuman, Argentina: Kluwer Academic/Plenum.

Barbour, M. T., Gerritsen, J., Snyder, B. D. & Stribling, J. B. 1999. *Rapid Bioassessment Protocols for Use in Streams and wadeable Rivers: Periphyton, Benthic Macroinvertebrates and Fish.* Washington, D.C.: U.S. Environmental Protection Agency; Office of Water;.

Barbour, M. T., Stribling, J. B. & Karr, J. R. 1995. Multimetric approach for establishing biocriteria and measuring biological condition. In: *Biological assessment and criteria. Tools for water resource planning and decision making* (Ed. by Davis, W. S. & Simon, T. P.). Boca Raton, Florida: Lewis Publishers.

Barr, C., M. 1998. *Bob Hasan, the rise of Apkindo, and the shifting dynamics of control of Indonesia's timber sector.* Cornell University Southeast Asia Program.pp. 35.

Belluzo, W. A two sample permutation test for contingent valuation studies. http:\\www.sbe.org.br/ebe24/022.pdf.

Bent, G. C. 2001. Effects of forest-management activities on runoff components and ground-water recharge to Quabbin Reservoir, central Massachusetts. *Forest Ecology and Management*, **143,** 115-129.

Bertault, J. G. & Sist, P. 1997. An Experimental Comparison of Different Harvesting Intensities with Reduced-Impact and Conventional Logging in East Kalimantan, Indonesia. *Forest Ecology and Management*, **94,** 209-218.

Boltz, F., Holmes, T., P. & Carter, D. R. 2003. Economic and environmental impacts of conventional and reduced-impact logging in Tropical South America: a comparative review. *Forest Policy and Economics*, **5,** 69-81.

Bottger, K. 1975. Studies on productivity of Kalengo-stream in Central Africa. *Archiv für Hydrobiologie*, **75** (1), 1-31.

Bourassa, N. & Morin, A. 1995. Relationships between size structure of invertebrate assemblages and trophy and substrate composition in streams. *Journal of the North American Benthological Society*, **14,** 393-403.

Brooker, M. P. & Hemsworth, R. J. 1978. Effect of release of an artificial discharge of water on invertebrate drift in R Wye, Wales. *Hydrobiologia*, **59,** 155-163.

Brown, G. W. & Krygier, J. T. 1971. Clear-cut logging and sediment production in the Oregon Coast Range. *Water Resources Research*, **7,** 1189-1198.

Bryce, S. A. & Clarke, S. E. 1996. Landscape-Level Ecological Regions - Linking State-Level Ecoregion Frameworks with Stream Habitat Classifications. *Environmental Management*, **20,** 297-311.

Caloz, R. & Collet, C. 2001. *Précis de télédétection: traitements numériques d'images de télédétection*. Sainte-Foy (Québec): Presses de l'Université du Québec.

Cannon, C. H., Peart, D. R. & Leighton, M. 1998. Tree Species Diversity in Commercially Logged Bornean Rainforest. *Science*, **281,** 1366-1368.

Cannon, C. H., Peart, D. R., Leighton, M. & Kartawinata, K. 1994. The structure of lowland rainforest after selective logging in West Kalimantan, Indonesia. *Forest Ecology and Management*, **67,** 49-68.

Casson, A. & Obidzinski, K. 2002. From New Order to regional autonomy: shifting dynamics of "illegal" logging in Kalimantan, Indonesia. *World Development*, **30,** 2133-2151.

Chappell, N. A., Bidin, K. & Tych, W. 2001. Modelling rainfall and canopy controls on net-precipitation beneath selectively-logged tropical forest. *Plant Ecology*, **153,** 215-229.

Chappell, N. A., Ternan, J. L. & Bidin, K. 1999. Correlation of physicochemical properties and sub-erosional landforms with aggregate stability variations in a tropical ultisol disturbed by forestry operations. *Soil & Tillage Research*, **50,** 55-71.

Chiasson, A. 2000. Water quality and biodiversity as assessed by macroinvertebrate analysis in the Grand Lake Ecoregion of the Fundy Model Forest. *Réseau de Forêts Modèles*.

Church, M. 1994. Channel morphology and typology. In: *The Rivers Handbook* (Ed. by Calow, F. & Petts, G. E.), pp. 1185-1202. Oxford: Blackwell Scientific Publication.

Collier, K. J. & Bowman, E. J. U. (in press). Role of wood in pumice-bed streams; I: Impacts of post-harvest management on water quality, habitat and benthic invertebrates. *Forest Ecology and Management*, **In Press**.

Connell, J. H. 1978. Diversity in tropical rain forests and coral reefs. *Science*, **199,** 1302-1310.

Culp, J. M., Walde, S. J. & Davies, R. W. 1983. Relative importance of substrate particle-size and detritus to stream benthic macroinvertebrate microdistribution. *Canadian Journal of Fisheries and Aquatic Science*, **40,** 1568-1574.

Cummins, K. W., Cushing, C. E. & Minshall, G. W. 1995. Introduction: an overview of stream ecosystems. In: *River and stream ecosystems* (Ed. by Cushing, C. E., Cummins, K. W. & Minshall, G. W.), pp. 1-8. Amsterdam: Elsevier Science.

Death, R. G. 2002. Predicting invertebrate diversity from disturbance regimes in forest streams. *Oikos*, **97,** 18-30.

DeShon, J. E. 1995. Development and application of the invertebrate community index (ICI). In: *Biological assessment and criteria: tools for water resource planning and decision making* (Ed. by Davis, W. S. & Simon, T. P.), pp. 217-243. Boca Raton, Florida: Lewis.

Digby, P. G. N. & Kempton, R. A. 1987. *Multivariate analysis of ecological communities*. London, New York: Chapman & Hall.

Dobson, M., Magana, A., Mathooko, J. M. & Ndegwa, F. K. 2002. Detritivores in Kenyan highland streams: more evidence for the paucity of shredders in the tropics? *Freshwater Biology*, **47,** 909-919.

Doledec, S. & Chessel, D. 1994. Co-inertia analysis: an alternative method for studying species-environment relationships. *Freshwater Biology***,** 277-294.

Douglas, I., Bidin, K., Balamurugan, G., Chappell, N. A., Walsh, R. P. D., Greer, T. & Sinum, W. 1999. The role of extreme events in the impacts of selective tropical forestry on erosion during harvesting and recovery phases at Danum Valley, Sabah. *Philosophical Transactions of the Royal Society of London. Series B.*, **354,** 1749-1761.

Douglas, I., Greer, T., Bidin, K. & Spilsbury, M. 1993. Impacts of rainforest logging on river systems and communities in Malaysia and Kalimantan. *Global Ecology and Biogeography Letters*, **3**.

Douglas, I., Spencer, T., Greer, T., Bidin, K., Sinun, W. & Meng, W. W. 1992. The impact of selective logging on stream hydrology, chemistry and sediment loads in the Ulu Segama rain forest, Sabah, Malaysia. *Phil. Trans. R. Soc. Lond. B*, **335,** 397-406.

Dudgeon, D. 1988. Hong Kong freshwaters: seasonal influences on benthic communities. *Verh. Internat. Verein. Limnol.*, **23,** 1362-1366.

Dudgeon, D. 1992. Endangered Ecosystems - A Review of the Conservation Status of Tropical Asian Rivers. *Hydrobiologia*, **248,** 167-191.

Dudgeon, D. 1995. The ecology of rivers and streams in Tropical Asia. In: *Ecosystems of the world: river and stream ecosystems* (Ed. by David Goodall, C. E. C., KW Cummins et G.W. Minshall), pp. 615-656: Elsevier.

Dudgeon, D. 1999. *Tropical Asian Streams: zoobenthos, ecology and conservation.* Hong Kong.

Dudgeon, D., Arthington, A. H., Chang, W. Y. B., Davies, J., Humphrey, C. L., Pearson, R. G. & Lam, P. K. S. 1994. Conservation and management of tropical Asian and Australian inland waters: problems, solutions and prospects. *Mitt. Internat. Verein. Limnol.*, **24**, 369-386.

Duelli, P. 1997. Biodiversity evaluation in agricultural landscapes - an approach at 2 different scales.*Agricultural Ecosystems & Environment*, **62,** 81-91.

Elliott, C. 2000. *Forest certification: a policy perspective*. Jakarta, Indonesia: Centre for International Forestry Research.

Erman, D. C. & Erman, N. 1984. The response of stream macroinvertebrates to substrate size and heterogeneity. *Hydrobiologia*, **108,** 75-82.

FAO/UNESCO. 1974. *Soil map of the world*. Paris.

Fatawi, M. & Mori, T. 2000. Description of forest and forestry in East Kalimantan. In: *Rainforest Ecosystems of East Kalimantan: El Nino, drought, fire and human impacts* (Ed. by al., G. e.). Tokyo: Springler-Verlag.

Fimbel, A. & O'Brien, T. G. 1999. Faunal surveys in unlogged forest of the Inhutani II Malinau timber concession. pp. 40: Wildlife Conservation Society.

Fisher, S. G., Grimm, N. B., Marti, E., Holmes, R. M. & Jones, J. B. 1998. Material spiraling in stream corridors: a teslescoping ecosystem model. *Ecosystems*, **1,** 19-34.

Foody, G. M., Cutler, M. E., McMorrow, J., Pelz, D., Tangki, H., Boyd, D. S. & Douglas, I. 2001. Mapping the biomass of Bornean tropical forest from remotely sensed data. *Global Ecology and Biogeography,* **10,** 379-387.

Foody, G. M., Cutler, M. E., McMorrow, J., Pelz, D., Tangki, H., Boyd, D. S. & Douglas, I. 2000. Mapping biomass and forest disturbance in Bornean tropical rainforest. In: *The 28th International Symposium on Remote sensing of Environment*. Cape Town, South Africa.

Forman, R. T. T. 1995. Some general principles of landscape and regional ecology. *Landscape Ecology,* **10,** 133-142.

Forman, R. T. T. & Godron, M. 1986. *Landscape ecology.* New York: John Wiley & Sons.

Frissel, C. A., Liss, W. J., Warren, C. E. & Hurley, M. D. 1986. A hierarchical framework for stream habitat classification: viewing streams in a watershed context. *Environmental Management*, **10,** 199-214.

Giesen, W. 1994.Indonesia's major freshwater lakes: a review of current knowledge, development processes and threats. *Mitt. Internat. Verein. Limnol.*, **24**, 369-386.

Gilliam, F. S. & Roberts, M. R. 1995. Impacts of forest management on plant diversity. *Ecological Applications,* **5,** 911-912.

Gotelli, N. J. & Colwell, R. K. 2001. Quantifying biodiversity: procedures and pitfalls in the measurement and comparison of species richness. *Ecology Letters,* **4,** 379-391.

Gotelli, N. J. & Entsminger, G. L. 2001. EcoSim: null models software for ecology. Version 7.0. *Acquired Intelligence Inc. & Kesey-Bear.*

Growns, I. O. & Davis, J. A. 1991. Comparison of the macroinvertebrate communities in streams in logged and undisturbed catchments 8 years after harvesting. *Australian Journal of Marine and Freshwater Resource***,** 689-706.

Gurtz, M. E. & Wallace, J. B. 1984. Substrate-mediated response of stream invertebrates to disturbance. *Ecology,* **65,** 1556-1569.

Haefner, J. D. & Wallace, J. B. 1981. Shifts in aquatic insect populations in a 1st-order Southern Appalachian stream following a decade of old field succession. *Canadian Journal of Fisheries and Aquatic Science,* **38,** 353-359.

Haila, Y. & Kouki, J. 1994. The phenomenon of biodiversity in conservation biology. *Annales Zoologici Fennici,* **31,** 5-18.

Hauer, F. R. & Lamberti, G. A. 1996. Methods in Stream Ecology. pp. 674: Academic Press.

Hawkes, H. A. 1997. Origin and development fo the Biological Monitoring Working Party Score System. *Water Research,* **32,** 964-968.

Hawkins, C. P., Murphy, M. L. & Anderson, N. H. 1982. Effects of canopy, substrate composition, and gradient on the structure of macroinvertebrate communities in cascade range streams of Oregon. *Ecology,* **63,** 1840-1856.

Hewlett, J. D. & Helvey, J. D. 1970. Effects of forest clear-felling on the storm hydrograph. *Water Resources Research,* **6,** 768-782.

Hilsenhoff, W. L. 1987. An improved index of organic stream pollution. *Great Lakes Entomologist,* **20,** 31-39.

Holmes, T. P., Blate, G. M., Zweede, J. C., Pereira, R. J., Barreto, P., Boltz, F. & Bauch, R. 2002. Financial and ecological indicators of reduced impact logging performance in the eastern Amazon. *Forest Ecology and Management,* 93-110.

Hornbeck, J. W., Pierce, R. S. & Federer, C. A. 1970. Streamflow changes after forest clearing in New England. *Water Resources Research,* **6,** 1124-1131.

Horton, R. E. 1945. Erosional development of streams and their drainage basins: hydrophysical approach to quantitative morphology. *Bulletin of the Geological Society of America,* **56,** 275-350.

Hynes, H. B. N. 1975. The stream and its valley. *Verh. Internat. Verein. Limnol.,* **19,** 1-15.

Illies, J. 1971. Emergence 1969 on Breitenbach.1.Schlitz studies on productivity. *Archiv für Hydrobiologie,* **64,** 14-15.

Innes, J. L. & Koch, B. 1998. Forest Biodiversity and Its Assessment by Remote-Sensing. *Global Ecology and Biogeography,* **7,** 397-419.

ITTO. 1992a. Criteria for the measurement of sustainable tropical forest management. Yokohama: ITTO.

Jackson, S. M., Fredericksen, T. S. & Malcolm, J. R. 2002. Area disturbed and residual stand damage following logging in a Bolivian tropical forest. *Forest Ecology and Management,* 271-283.

Johnston, C. A. 1998. *Geographic Information Systems in Ecology*. Oxford: Blackwell Science Ltd.

Junk, W. J., Bayley P. B. & Sparks R. E. 1989. The flood pulse concept in river-floodplain systems. In *Proceedings of the International Large River Symposium* (D.P. Dodge, ed.), pp 110-127. Can. Spec. Publ. Fish. Aquat. Sci. 106.

King, J. M. 1983. Abundance, biomass and diversity of benthic macro-invertebrates in a western Cape river, South Africa. *Transactions of the Royal Society for South Africa,* **45,** 11-28.

Klassen, A. W. 1999. Interim report on the implementation of a reduced impact logging trial in the Inhutani II concession, Malinau (unpublished). Forestec Consulting Ltd.

Kottelat, M. & Whitten, A. J. 1996a. Freshwater fishes of western Indonesia and Sulawesi: additions and corrections. Periplus, Jakarta.

Kottelat, M. & Whitten, A. J. 1996b. Freshwater biodiversity in Asia with special reference to fish. World Bank Techn. Pap., **343**, i-ix + 1-59

Lake, P. S. 2000. Disturbance, patchiness, and diversity in streams. *Journal of North American Benthological Society,* **19,** 573-592.

Lammert, M. & Allan, J. D. 1999. Assessing Biotic Integrity of Streams - Effects of Scale in Measuring the Influence of Land Use/Cover and Habitat Structure on Fish and Macroinvertebrates. *Environmental Management,* **23,** 257-270.

Lancaster, J. 1999. Small-scale movements of lotic macroinvertebrates with variations in flow. *Freshwater Biology,* **41,** 605-619.

Landolt, P. & Sartori, M. 2001. Ephemeroptera in Switzerland. In: *Trends in research in Ephemeroptera & Plecoptera* (Ed. by Dominguez, E.), pp 285-300. *IX International Conference on Ephemeroptera and XIII International Symposium on Plecoptera,*Tucuman, Argentina: Kluwer Academic/Plenum.

Lang, C. & Reymond, O. 1995. An improved index of environmental quality for Swiss rivers based on benthic invertebrates. *Aquatic Sciences*, **57,** 172-180.

Lang, D. & Hubblel, D. (unpublished). The amphibians and reptiles of Malinau region, Bulungan, East Kalimantan.

Legendre, P. & Legendre, L. 1998. *Numerical Ecology.* Amsterdam, the Netherlands: Elsevier Science B.V.

Lehmusluoto, P., Machbub, B., Terangna, N., Achmad, F., Boer, L., Sembiring, S., Setiadji, B., Priadie, B., Timotius, K. H. & Goeltenboth, F. 1999. Limnology in Indonesia: from the legacy of the past to the prospects for the future. In: *Limnology in Developing Countries* (Ed. by Wetzel, R. G. a. G., B.), pp. 119-234: International Association for limnology (SIL).

Lelek, A. 1985. About a source of nutrients in the tropical River Rajang (N Borneo) in relation to future impoundment. *Verh. Internat. Verein. Limnol.***,** 2115-2118.

Lemly, A. D. 1982. Modification of benthic insect communities in polluted streams - combined effects of sedimentation and nutrient enrichment. *Hydrobiologia*, **87,** 229-245.

Lemmon, P. E. 1957. A new instrument for measuring forest overstory density. *Journal of forestry*, **55,** 667-668.

Lenat, D. R., Penrose, D. L. & Eagleson, K. W. 1981. Variable effects of sediment addition on stream benthos. *Hydrobiologia*, **79,** 187-194.

Levin, S. 1992. The problem of pattern and scale in ecology. *Ecology*, **73,** 1943-1967.

Lindenmayer, D. B., Margules, C. R. & Botkin, D. B. 2000. Indicators of biodiversity for ecologically sustainable forest management. *Conservation Biology*, **14,** 941-950.

Lorenz, C. M., Van Dijk, G. M., Van Hattum, A. G. M. & Cofino, W. P. 1997. Concepts in river ecology: implications for indicator development. *Regulated Rivers: Research & Management*, **13,** 501-516.

Ludwig, J. A. & Reynolds, J. F. 1988. *Statistical ecology: a primer on methods and computing*. John Wiley & Sons.

Lundberg, J. G., Kottelat, M., Smith, G. R., Stiassny, M. L. J. & Gill, A. C. 2000. So many fishes, so little time: an overview of recent ichthyological discovery in continental waters. *Ann. Missouri Bot. Gard*., **87**, 26-62.

MacKinnon, K., Hatta, G., Halim, H. & Mangalik, A. 1996. *The ecology of Kalimantan*. Eric Oey.

Magurran, A. E. 1988. *Ecological diversity and its measurement.* London: Croom Helm.

Marchant, R., Metzeling, L., Graesser, A. & Suter, P. 1985. The organisation of macroinvertebrate communities in the major tributaries of the La Trobe river, Victoria, Australia. *Freshwater Biology*, **15,** 315-331.

Martin-Smith, K. M., Laird, L. M., Bullough, L. & Lewis, M. G. 1999. Mechanisms of maintenance of tropical freshwater fish communities in the face of disturbance. *Phil. Trans. R. Soc. Lond. B*, **354**, 1803-1810.

Matthaei, C. D. & Townsend, C. R. 2000. Long-term effects of local disturbance history on mobile stream invertebrates. *Oecologia*, **125,** 119-126.

McCafferty, W. P. 2001. The gentle quest: 200 years in search of North American mayflies. In: *Trends in research in Ephemeroptera & Plecoptera* (Ed. by Dominguez, E.), pp 21-36. *IX International Conference on Ephemeroptera and XIII International Symposium on Plecoptera*,Tucuman, Argentina: Kluwer Academic/Plenum.

McElravy, E. P., Lamberti, G. A. & Resh, V. H. 1989. Year-to-year variation in the aquatic macroinvertebrate fauna of a northern California stream. *J. N. Am. Benthol. Soc.*, **8,** 51-63.

Merritt, R. W. & Cummins, K. W. 1978. *An introduction to the aquatic insects of North America*. Dubuque, Iowa: Merritt, R. & Cummins K.

Minshall, G. W. 1981. Structure and temporal variations of the benthic macroinvertebrate community inhabiting Mink Creek, Idaho, USA, a third order rocky mountain stream. *Journal of freshwater ecology*, **1,** 13-26.

Minshall, G. W. 1984. Aquatic insect-substratum relationships. In: *The ecology of aquatic insects* (Ed. by Resh, V. H. & Rosenber, D. M.), pp. 358-400. New York: Praeger.

Minshall, G. W., Royer, T. V. & Robinson, C. T. 2001. Response of the Cache Creek macroinvertebrates during the first 10 years following disturbance by the 1988 Yellowstone wildfires. *Canadian Journal of Fisheries and Aquatic Sciences*, **58,** 1077-1088.

Nepstad, D. C., Verrissimo, A., Alencar, A., Nobre, C., Lima, E., Lefebre, P., Schlesinger, P. & Potter, C. 1999. Large-scale impoverishment of Amazonian forests by logging and fire. *Nature*, **398,** 505-508.

Neumann, M. & Dudgeon, D. 2002. The impact of agricultural runoff on stream benthos in Hong Kong, China. *Water Research***,** 3103-3109.

Newbold, J. D., Erman, D. C. & Roby, K. B. 1980. Effects of logging on macroinvertebrates in streams with and without buffer strips. *Can. J. Fish. Aquat. Sci*, **37,** 1076-1085.

Noel, D. S., Martin, C. W. & Federer, C. A. 1986. Effects of forest clearcutting in New England on stream macroinvertebrates and Periphyton. *Environmental Management*, **10,** 661-670.

Nontji, A. 1994. The status of limnology in Indonesia. *Mitt. Internat. Verein. Limnol.*, **24**, 369-386.

Noss, R. F. 1990. Indicators for monitoring biodiversity: a hierarchical Approach. *Conservation Biology*, **4,** 355-363.

NRMP. 1993. Mid term report: guidelines and implementation issues concerning natural production forest management. Jakarta: Natural Ressources Management Project.

Oka, T., Iskandar, E. & Ghozali, D. I. 2000. Effects of forest fragmentation on the behavior of bornean gibbons. In: *Rainforest ecosystems of East Kalimantan: El Nino, drought, fire and human impacts* (Ed. by Guhardja, E., Fatawi, M., Sutisna, M., Mori, T. & Ohta, S.), pp. 229-242. Tokyo: Springer-Verlag.

O'Neill, R. V., DeAngelis, D. L., Waide, J. B. & Allen, T. F. H. 1986. *A Hierarchical Concept of Ecosystems*. Princeton, New Jersey, USA: Princeton University Press.

Palmer, M. A., Bely, A. E. & Berg, K. E. 1992. Response of invertebrates to lotic disturbance: a test of the hyporheic refuge hypothesis. *Oecologia*, **89,** 182-194.

Peckarsky, B. L. 1985. Do predaceous stoneflies and siltation affect the structure of stream insect communities colonizing enclosures. *Canadian Journal of Zoology*, **63,** 1519-1530.

Pescador, M. L., Hubbard, M. D. & Zuniga, M. d. C. 2001. The status of the taxonomy of the mayfly (Ephemeroptera) fauna of South America. In: *Trends in research in Ephemeroptera & Plecoptera* (Ed. by Dominguez, E.), pp 37-42. *IX International Conference on Ephemeroptera and XIII International Symposium on Plecoptera*,Tucuman, Argentina: Kluwer Academic/Plenum.

Petts, G. & Calow, P. 1996a. River biota: Diversity and Dynamics. pp. 257: Blackwell Science.

Petts, G. & Calow, P. 1996b. River Flows and Channel Forms. pp. 262: Blackwell Science.

Pickett, S. T. A. & Cadenasso, M. L. 1995. Landscape ecology:spatial heterogeneity in ecological systems. *Science*, **269,** 331-334.

Plafkin, J. L., Barbour, M. T., Porter, K. D., Gross, S. K. & Hughes, R. M. 1989. *Rapid bioassessment protocols for use in stream and rivers: benthic macroinvertebrates and fish.* Washington, DC: US Environmental Protection Agency.

Pringle, C. M. & Ramirez, A. 1998. Use of both benthic and drift sampling techniques to assess tropical stream invertebrate communities along an altitudinal gradient, Costa Rica. *Freshwater Biology*, **39,** 359-373.

Rachmatika, I. 2000. Fish faunal in Bulungan research forest, Malinau, East Kalimantan. LIPI.

Reice, S. R. 1985. Experimental disturbance and the maintenance of species diversity in a stream community. *Oecologia*, **67,** 90-97.

Resh, V. H., Brown, A. V., Covich, A. P., Gurtz, M. E., Li, G. W., Minshall, G. W., Reice, S. R., Sheldon, A. L., Wallace, J. B. & Wissmar, R. 1988. The role of disturbance in stream ecology. *Journal of the North American Benthological Society*, **7,** 433-455.

Resh, V. H., Norris, R. H. & Barbour, M. T. 1995. Design and Implementation of Rapid Assessment Approaches for Water-Resource Monitoring Using Benthic Macroinvertebrates. *Australian Journal of Ecology*, **20,** 108-121.

Resh, V. H. & Rosenberg, D. M. 1989. Spatial-temporal variability and the study of aquatic insects. *Can. Ent.*, 941-963.

Rishel, G. B., Lynch, J. A. & Corbett, E. S. 1982. Seasonal stream temperature-changes following forest harvesting. *Journal of Environmental quality*, **11,** 112-116.

Robinson, C. T. & Rushforth, S. R. 1987. Effects of physical disturbance and canopy cover on attached diatom community structure in an Idaho stream. *Hydrobiologia*, **154,** 49-59.

Rodier, J. 1984. *L'analyse de l'eau*. Paris.

Rosenberg, D. M. & Resh, V. H. 1993. Freshwater biomonitoring and benthic macroinvertebrates. pp. 488. New York: Chapman & Hall.

Roux, M. 1991. Basic procedures in hierarchical cluster-analysis. In: *Eurocourse on applied multivariate analysis in SAR and environmental studies* (Ed. by ISPRA, J. R. C.), pp. 115-135. Italy: Kluwer Academic publ. Dordrecht.

Sagar, P. M. 1986. The effects of floods on the invertebrate fauna of a large, unstable braided river. *New Zealand Journal of Marine and Freshwater research*, **20,** 37-46.

Sartori, M., Derleth, P. & Gattolliat, J. L. (in press). New data about the mayflies (Ephemeroptera) from Borneo. In: *Proceedings of the Xth International conference on Ephemeroptera* (Ed. by Gaino, E.). Perugia.

Schälchli, U. 1992. The clogging of coarse gravel river beds by fine sediment. *Hydrobiologia*, **235/236,** 189-197.

SEQ-Eau. 2003. Système d'évaluation de la quality de l'eau des cours d'eau (SEQ-Eau). France: Ministère de l'Ecologie et du Développement Durable & Agences de l'eau.

Sève, J. 1999. A review of Forestry sector policy issues in Indonesia. pp. 39. Jakarta, Indonesia: Natural Resources Management Program.

Siegel, A. F. 1988. *Statistics and data analysis: an introduction*. New York: Wiley, Cop.

Siegert, F. & Hoffmann, A. A. 2000. The 1998 forest fires in East Kalimantan (Indonesia): a quantitative evaluation using high resolution multitemporal ERS-2 SAR images and NOAA-AVHRR Hotspot data. *Remote Sensing Environment*, **72,** 64-77.

Sist, P. & Nguyen-Thé, N. 2002. Logging damage and the subsequent dynamics of a dipterocarp forest in East Kalimantan (1990-1996). *Forest Ecology and Management*, 85-103.

Sist, P., Nolan, T., Bertault, J. G. & Dykstra, D. 1998. Harvesting Intensity Versus Sustainability in Indonesia. *Forest Ecology and Management*, **108,** 251-260.

Sist, P., Sheil, D., Kartawinata, K. & Priyadi, H. 2002. Reduced-impact logging in Indonesian Borneo: some results confirming the need for new silvicultural prescriptions. *Forest Ecology and Management*, **In press**.

Smith, M. J., Kay, W. R., Edward, D. H. D., Papas, P. J., Richardson, K. S. J., Simpson, J. C., Pinder, A. M., Cale, D. J., Horwitz, P. H. J., Davis, J. A., Yung, F. H., Norris, R. H. & Halse, S. A. 1999. AusRivAs: using macroinvertebrates to assess ecological condition of rivers in Western Australia. *Freshwater Biology*, **41,** 269-282.

Southwood, T. 1977. Habitat templet for ecological strategies. *Journal of animal ecology*, **46,** 337-365.

Stanford, J. A. & Ward, J. V. 1983. Insect species diversity as a function of environmental variability and disturbance in stream systems. In: *Stream ecology: application and testing of general ecological theory* (Ed. by Barnes, J. R. & Minshall, G. W.), pp. 265-278. New York: Plenum Press.

Statzner, B. & Higler, B. 1986. Stream hydraulics as a major determinant of benthic invertebrate zonation patterns. *Freshwater Biology*, **16,** 127-139.

Stone, M. K. & Wallace, J. B. 1998. Long-term recovery of a mountain stream from clear-cut logging: the effects of forest succession on benthic invertebrate community structure. *Freshwater Biology*, 151-169.

Stone, T. A. & Lefebvre, P. 1998. Using multi-temporal satellite data to evaluate selective logging in Para, Brazil. *International Journal of Remote Sensing*, **19,** 2517-1526.

Swank, W. T., Vose, J. M. & Elliott, K. J. 2001. Long-term hydrologic and water quality responses following commercial clearcutting of mixed hardwoods on a southern Appalachian catchment. *Forest Ecology and Management*, **143,** 163-178.

Tachet, H., Richoux, P., Bournaud, M. & Usseglio-Polatera, P. 2000. *Invertébrés d'eau douce: systématique, biologie, ecologie*. Paris: CNRS Editions.

Thioulouse, J., Chessel, D., Dolédec, S. & Olivier, J. M. 1997. ADE-4: a multivariate analysis and graphical display software. *Statistics and Computing*, **7,** 75-83.

Thompson, R. C., Wilson, B. J., Tobin, M. L., Hill, A. S. & Hawkins, S. J. 1996. Biologically generated habitat provision and diversity of rocky shore organisms at a hierarchy of spatial scales. *Journal of Experimental Marine Biology and Ecology*, **202,** 73-84.

Thorup, J. 1970. Influence of a short-termed flood on a springbrook community. *Archiv für Hydrobiologie*, **66,** 447-&.

Townsend, C. R., Arbuckle, C. J., Crowl, T. A. & Scarsbrook, M. R. 1997. The relationship between land use and physicochemistry, food resources and macroinvertebrate communities in tributaries of the Taieri River, New Zealand: a hierarchically scaled approach. *Freshwater Biology*, **37,** 177-191.

Townsend, C. R. & Scarsbrook, M. R. 1997. The intermediate disturbance hypothesis, refugia, and biodiversity in streams. *Limnol. Oceanogr.*, **42,** 938-949.

Turner, M. G. 1989. Lanscape ecology: the effect of pattern on process. In:*Annual Review of Ecology and Systematics*. 20.

Underwood, A. J. 1991. Beyond BACI: experimental designs for detecting human environmental impact on temporal variations in natural populations. *Australian Journal of Marine and Freshwater Resources***,** 569-587.

Vannote, R. L., Minshall, G. W., Cummins, K. W., Sedell, J. R. & Cushing, C. E. 1980. The River Continuum Concept. *Canadian Journal of Fisheries and Aquatic Sciences*, **37,** 130-137.

Vannote, R. L. & Sweeney, B. W. 1980. Geographic analysis of thermal equilibria: a conceptual model for evaluationg the effect of natural and modified thermal regimes on aquatic insect communities. *The American Naturalist*, **115,** 667-695.

Wallace, J. B. & Grubaugh, J. W. 1996. Transport and storage of FPOM. In: *Methods in Stream Ecology* (Ed. by Hauer, F. R. & A., L. G.), pp. 191-215. London: Academic Press.

Wallace, J. B. & Gurtz, M. E. 1986. Response of Baetis mayflies (Ephemeroptera) to catchment logging. *The American Midland Naturalist*, **115,** 25-41.

Wallace, J. B. & Merritt, R. W. 1980. Filter-feeding ecology of aquatic insects. *Annual Review of Entomology*, **25,** 103-132.

Walsh, R. P. D. 1992. Representation and classification of tropical climates for ecological purposes using the perhumidity index. *Swansea Geographer*, **29,** 109-129.

Walsh, R. P. D. 1996. Drought frequency changes in Sabah and adjacent parts of northern Borneo since the late nineteenth century and possible implications for tropical rain forest dynamics. *Journal of Tropical Ecology*, **12,** 385-407.

Ward, J. V. 1989. The four-dimensional nature of lotic ecosystems. *J. N. Am. Benthol. Soc.*, **8,** 2-8.

Ward, J. V. 1998. Riverine landscapes: biodiversity patterns, disturbance regimes, and aquatic conservation. *Biological Conservation*, **83,** 269-278.

Weishampel, J. F., Godin, J. R. & Henebry, G. M. 2001. Pantropical dynamics of "intact" rain forest canopy texture. *Global Ecology and Biogeography*, **10,** 389-397.

Welsch, D. A. & Venier, L. A. 1996. Binoculars and satellites - Developing a conservation framework for boreal forest wildlife at varying scales. *Forest ecology and management*, **85,** 53-65.

Winterbourn, M. J., Rounick, J. S. & Cowie, B. 1981. Are New-Zealand stream ecosystems really different. *New Zealand Journal of Marine and Freshwater research*, **15,** 321-328.

Wonnacott, T. H. & Wonnacott, R. J. 1990. *Statistique: économie - gestion - sciences - médecine*. Paris: Economica.

Woodall, W. R. & Wallace, J. B. 1972. Benthic fauna in 4 small southern Appalachian streams. *American Midland Naturalist*, **88,** 393-&.

WorldBank. 2001. Indonesia: environment and natural resource management in a time of transition. The World Bank.

Yule, C. M. 1996a. The ecology of an aseasonal tropical river on Bougainville Island, Papua New Guinea. *Perspective in Tropical Limnology***,** 239-254.

Yule, C. M. 1996b. Spatial distribution of the invertebrate fauna of an aseasonal tropical stream on Bougainville Island, Papua New Guinea. *Arch. Hydrobiol.*, **137,** 227-249.

Yule, C. M. & Pearson, R. G. 1996. Aseasonality of benthic invertebrates in a tropical stream on Bougainville Island, Papua New Guinea. *Arch. Hydrobiol*, **137,** 95-117.

Zweig, L. D. & Rabeni, C. F. 2001. Biomonitoring for deposited sediment using benthic invertebrates: a test on 4 Missouri streams. *Journal of North American Benthological Society,* **20,** 643-657.

List of figures

List of tables

Appendix I

Environmental variables for each sample

samples	sampling date	year logged	Time after logging (y=year; m=month)	stream size <6m	stream size >6m	Watershed	Depth (m)	Flow velocity (m/s)	Water temp. (°C)	Air temp. (°C)	Conductivity (µs/cm)
1.1.1	05.07.00	1996	4-5 y	X		Rian	0.35	0.4	25.8	26.5	100.1
1.1.3	20.04.01	2000	6 m	X		Rian	0.26	0.2	26.1	25.8	90
1.2.1	07.07.00	1996	4-5 y	X		Rian	0.3	0.4	25	25.8	97.5
1.2.3	18.04.01	2000	6 m	X		Rian	0.1	0.35	25.1	25.7	91
2.1.1	01.07.00	2000	6 m	X		Seturan	0.6	0.9	25	26	67.5
2.1.3	27.03.01	2000	6 m	X		Seturan	0.4	0.75	24.5	25.2	81.7
4.1.1	08.07.00	1995	4-5 y		X	Rian	0.4	0.85	26.4	28.8	125.5
4.2.1	12.07.00	1995	4-5 y	X		Rian	0.2	0.4	25.1	28.3	135.1
4.3.1	13.07.00	1995	4-5 y		X	Rian	0.3	1.4	25.7	30.8	101.5
4.3.3	17.04.01	2001	6 m		X	Rian	0.1	1.4	26	25.9	136
5.1.1	18.07.00	2000	6 m		X	Seturan	0.8	0.8	26.4	25.8	104.4
5.1.3	10.04.01	2000	6 m		X	Seturan	0.6	0.8	26.5	26	160.5
5.2.1	19.07.00	2000	6 m		X	Seturan	0.6	0.8	26.1	26.5	103.5
5.3.1	08.08.00	Ref.	Ref.		X	Seturan	0.7	0.9	24.7	25.3	66
5.3.3	11.04.01	2000	6 m		X	Seturan	0.4	0.9	25.2	26.9	107
5.4.1	19.08.00	2000	6 m		X	Seturan	0.5	0.75	24.7	24.9	96
6.3.1	29.06.00	Ref.	Ref.	X		Seturan	0.25	0.7	23.9	24.2	61
7.1.1	17.06.00	Ref.	Ref.	X		Seturan	1.0	0.9	23.8	23.8	74
7.1.3	05.04.01	2000	6 m	X		Seturan	0.55	0.5	24.4	25.2	14.8
8.1.1	18.06.00	2000	6 m	X		Seturan	0.25	0.8	24.1	26	62
8.1.3	02.04.01	2000	6 m	X		Seturan	0.35	0.52	24.4	26	9.4
8.2.1	21.06.00	Ref.	Ref.	X		Seturan	0.4	0.85	23.7	24.6	59.8
8.2.3	04.04.01	2000	6 m	X		Seturan	0.3	0.6	23.8	23.6	16
8.3.1	16.08.00	2000	6 m	X		Seturan	0.35	0.8	24.3	25.1	72.5
8.3.3	16.04.01	2000	6 m	X		Seturan	0.4	0.8	24.6	25.6	86
9.1.1	20.06.00	1998	1-3 y	X		Seturan	0.3	0.65	25.3	27.4	11
9.1.3	29.03.01	1998	1-3 y	X		Seturan	0.3	0.65	24.5	24.3	4.7
10.1.1	23.06.00	1999	1-3 y	X		Rian	0.3	0.65	24.8	26	44
10.1.3	30.03.01	1999	1-3 y	X		Rian	0.5	0.7	24.5	24.6	9.3
11.1.1	10.07.00	1999	1-3 y	X		Seturan	0.35	0.4	25.9	28.6	16.2
11.1.3	26.03.01	1999	1-3 y	X		Seturan	0.3	0.4	24.4	25.1	7.4
12.1.1	11.07.00	1998	1-3 y	X		Rian	0.4	0.75	25.4	28	75.8
13.1.3	28.03.01	2000	6 m		X	Seturan	0.3	0.65	25.7	26.8	10.42
14.1.3	24.04.01	Ref.	Ref.	X		Seturan	0.16	0.4	24.7	25.4	19.4
14.2.3	26.04.01	Ref.	Ref.	X		Seturan	0.15	0.2	24.5	26.1	15.04
15.1.3	27.04.01	Ref.	Ref.	X		Seturan	0.25	0.3	25.2	26.4	10.8

Environmental variables for each sample

samples	Canopy opening (%)	substrate composition (%) bedrock	boulder	cobble	gravel	sand	siltclay	Mineral Matter < 1mm (gr)	Organic Matter (gr)	Organic Matter ratio (%)
1.1.1	8.3	0	5	20	70	5	0	25.01	1.56	6.26
1.1.3	6	0	5	15	70	5	5	6.51	1.00	15.33
1.2.1	11.4	0	0	40	50	10	0	8.44	0.76	9.01
1.2.3	9.5	0	5	5	60	20	10	5.99	0.62	10.35
2.1.1	5.2	60	20	5	5	10	0	20.03	1.02	5.11
2.1.3	6.5	30	10	10	5	5	40	25.12	1.12	4.46
4.1.1	42.1	1	5	20	70	4	0	69.54	3.4	4.89
4.2.1	11.2	0	0	35	60	5	0	47.67	3.27	6.85
4.3.1	23.7	0	45	40	10	5	0	17.67	1.09	6.15
4.3.3	33.1	0	5	10	80	5	0	27.36	1.44	5.25
5.1.1	36.7	0	40	40	10	0	10	44.57	1.84	4.12
5.1.3	40.3	0	30	40	5	20	10	26.01	1.34	5.16
5.2.1	41	0	30	40	25	0	5	15.25	0.98	6.40
5.3.1	9.9	10	40	40	5	0	5	9.55	1.10	11.52
5.3.3	23.4	0	5	50	40	5	0	23.65	1.29	5.44
5.4.1	15.9	0	10	50	35	5	0	16.36	1.34	8.18
6.3.1	6.5	1	30	20	49	0	0	16.61	1.95	11.73
7.1.1	9.6	78	15	5	2	0	0	7.03	1.29	18.3
7.1.3	21.2	40	30	5	15	5	5	8.41	1.3	15.41
8.1.1	51	0	1	5	64	30	0	56.54	1.34	2.38
8.1.3	31.2	1	20	20	50	9	0	17.88	0.87	4.89
8.2.1	5.7	5	30	30	35	0	0	8.01	1.29	16.16
8.2.3	3.4	10	20	10	50	10	0	26.96	2.3	8.55
8.3.1	34.5	5	40	30	15	5	5	33.61	1.21	3.59
8.3.3	25	1	45	35	10	9	0	21.63	1.3	5.99
9.1.1	22.9	0	0	90	10	0	0	29.37	0.46	1.57
9.1.3	13	0	1	34	60	5	0	17.59	0.25	1.43
10.1.1	19.8	1	20	30	5	44	0	61.06	0.80	1.32
10.1.3	7.3	1	30	20	34	10	5	62.90	0.96	1.53
11.1.1	25	0	1	50	40	9	0	32.39	0.78	2.41
11.1.3	7	1	1	44	44	10	0	42.57	0.51	1.20
12.1.1	12	0	10	30	30	30	0	30.18	1.36	4.52
13.1.3	86.3	0	5	45	25	25	0	33.37	2.29	6.87
14.1.3	3.9	0	20	59	20	1	0	14.63	1.31	8.93
14.2.3	4.7	0	15	40	40	5	0	23.96	2.01	8.38
15.1.3	8.3	0	5	45	30	20	0	63.65	3.55	5.58

Environmental variables for each samples

	Morphology types (%)						
samples	**cascade**	**riffle**	**run**	**pool**	**Forest type**	**Algae**	**substratum**
1.1.1	0	10	80	10	pioneer vegetation	absent	dark
1.1.3	0	0	50	50	pioneer vegetation	absent	dark
1.2.1	0	1	80	19	pioneer vegetation	absent	dark
1.2.3	0	10	45	45	pioneer vegetation	absent	dark
2.1.1	25	1	70	4	logged closed forest	absent	dark
2.1.3	10	30	10	50	logged closed forest	absent	light
4.1.1	0	13	75	2	secondary forest	absent	dark
4.2.1	0	10	90	0	secondary forest	absent	dark
4.3.1	0	10	60	30	secondary forest	absent	dark
4.3.3	0	40	60	0	secondary forest	abundant	dark
5.1.1	0	20	40	40	primary and secondary mixed forest	present	dark
5.1.3	0	20	40	40	primary and secondary mixed forest	abundant	dark
5.2.1	0	20	70	10	primary and secondary mixed forest	present	dark
5.3.1	0	10	40	50	primary forest	absent	dark
5.3.3	0	10	10	80	primary forest	abundant	dark
5.4.1	0	10	85	5	lightly logged forest	present	dark
6.3.1	30	20	50	0	primary forest	absent	dark
7.1.1	10	10	0	80	primary forest	absent	dark
7.1.3	10	10	10	70	logged open forest	present	light
8.1.1	0	40	60	0	logged open forest	abundant	light
8.1.3	0	40	50	10	logged open forest	abundant	light
8.2.1	0	10	79	1	primary forest	absent	dark
8.2.3	10	10	70	10	logged closed forest	absent	dark
8.3.1	0	40	60	10	logged open forest	absent	dark
8.3.3	0	50	40	10	logged open forest	absent	light
9.1.1	0	10	90	0	pioneer vegetation	absent	pale
9.1.3	0	20	10	70	pioneer vegetation	absent	pale
10.1.1	1	50	44	5	logged open forest	absent	light
10.1.3	0	60	20	20	logged open forest	absent	light
11.1.1	0	5	80	15	pioneer vegetation	absent	pale
11.1.3	0	20	40	40	pioneer vegetation	abundant	pale
12.1.1	0	10	80	10	pioneer vegetation	absent	light
13.1.3	0	20	50	30	primary and secondary mixed forest	present	dark
14.1.3	0	45	45	10	primary forest	absent	light
14.2.3	0	35	60	5	primary forest	absent	dark
15.1.3	0	10	90	0	primary forest	absent	dark

Appendix II

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TABLE 1. Density (number of individuals/m^2) and number of taxa for each samples. * represents the reference samples.

Samples	Streams < 6m	Streams > 6m	Density	Nb of taxa
111	X		437	34
113	X		863	40
121	X		600	43
123	X		783	41
211	X		663	24
213	X		360	25
411		X	543	32
421	X		573	43
431		X	533	37
433		X	815	36
511		X	667	34
513		X	2130	55
521		X	1060	37
*531		X	925	50
533		X	1533	49
541		X	1727	54
*631	X		310	29
*711	X		180	21
713	X		1303	48
811	X		757	38
813	X		1207	35
*821	X		407	32
823	X		333	30
831	X		1250	49
833	X		627	38
911	X		87	12
913	X		473	26
1011	X		240	13
1013	X		693	26
1111	X		587	21
1113	X		543	27
1211	X		740	34
*1413	X		590	47
*1423	X		1140	54
*1513	X		580	37

Curriculum vitae

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Education

1999 - 2003 PhD in ecosystem management - Swiss Federal Institute of Technology, Lausanne

1997 - 1999 M.S. Environmental Sciences - Swiss Federal Institute of Technology, Lausanne

1993 Tropical Botanical course (examination) - Botanical Conservatory and Garden of Geneva

1988 - 1993 B.S. Natural Sciences - University of Lausanne

1983 - 1986 Diploma in Business management - High School of Business, Lausanne

Research Experience

1999-2003 Ph D Thesis - Swiss Federal Institute of Technology (EPFL)

The present research is carried on at the Ecosystem Management (GECOS) laboratory, in collaboration with the Museum of Zoology in Lausanne and CIFOR (Centre for International Forestry Research), Bogor in Indonesia. It is sponsored by ZIL (Swiss Centre for International Agriculture). The title : Benthic macroinvertebrates and logging activities. A case study in a lowland tropical forest in East Kalimantan (Indonesian Borneo).

1998-1999 M.S. Environmental Sciences- Swiss Federal Institute of Technology (EPFL)

A nine-month research was undertaken at the Ecosystem Management (GECOS) laboratory on the following topic: assessment of forest quality as habitat for flora and fauna: case study of the Picoides tridactylus (woodpecker) in the spruce mountain forest in the "Pays d'Enhaut" region in Switzerland. Application of "dead wood" indicator for old growth forest.

1995-1996 Botanist - The World Conservation Union (IUCN), Cambodia

Compilation of a data base of useful plants in Kampuchea: 930 different species were represented with their various properties and uses, such as, medicinal, food, firewood, dyes, etc. Participation in a project for the rehabilitation of a Traditional Medicine Centre. Afterwards, on assignment by OXFAM-Novib to do an evaluation survey on the value of medicinal plants in Northeast Kampuchea, resulting in the delivery of a written report and recommendations.

1994-1995 Botanist - Botanical Conservatory and Garden of Geneva

Involvement in a "Political Ecology and Biodiversity" project, which took place in the Special Reserve of Manongarivo (North West Madagascar). The subject of the research was "The potential productivity of medicinal plants". The research entailed studying ways to remove different parts of plants (bark, leaves, roots,...) used in traditional medicine. It was conducted in order to estimate the extinction risk in the case of intensive exploitation.

Fellowship and grants

1999 - 2002 ZIL (Swiss Centre for International Agriculture) for 3 years PhD dissertation

2002 Société Académique Vaudoise for PhD dissertation

1997 EPFL for M.S. in Environmental Sciences

1994 Hoffmann La Roche foundation for 1 year study in Madagascar

1988 Canton de Vaud for 5 years at University for B.S. in natural Sciences

Publications and presentations

Derleth P., Sartori M., Schlaepfer R. and Gattolliat J.-L. (2001). How do logging activities influence the macroinvertebrate composition in a tropical stream systems (East Borneo, Indonesia) (poster). SIL (Societas Internationalis Limnologiae) 2001, XXVIII Congress, 4-10 February 2001, Melbourne, Australia. .

Derleth P., Sartori M., Schlaepfer R. and Gattolliat J.-L.(2001). Mayflies, a valuable tool to assess the impact of logging activities in tropical forest? (communication). International Joint Meeting: X International Conference on Ephemeroptera and XIV International Symposium on Plecoptera. 5-11 August 2001, Perugia, Italie.

Derleth P., Sartori M., Schlaepfer R. and Gattolliat J.-L. (2001). Ecological water quality: a valuable tool to assess the impact of logging activities on tropical forest?. ETFRN (European Tropical Forest Research Network) News 33: Forest and Water. Available on the internet at: http://www.etfrn.org/etfrn/newsletter/news33/index.html

Olivieri, G. (2001). Gestion des écosystemes: une expédition particulière, chercheuse Lausannoise à Bornéo. 24Heures newspaper, 12.11.2001.

Sartori, M., Derleth, P. and J.L. Gattolliat (in press). New data about the mayflies (Ephemeroptera) from Borneo. In: E. Gaino (Ed.), Proceedings of the Xth International Conference on Ephemeroptera, Perugia.

Derleth P., Sartori M., Schlaepfer R. and Gattolliat J.-L. (2002). L'exploitation des forêts tropicales est-elle vraiment compatible avec le maintient de la qualité de l'eau? (poster). Workshop at EPFL, "L'eau qui sort des bois....quand forêt durable rime avec eau potable" on November, 26th, 2002.

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