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Floristic Composition and Growth Dynamics of Riparian Forests in North-East Vietnam

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Floristic Composition and Growth Dynamics of Riparian Forests in North-East Vietnam

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Dedicated to My Family

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TABLE OF CONTENTS

Abbreviations

asl.	Above see level
B_a	Above ground biomass
CAI	Current annual increment (m^3)
cf.	Compare
D	SIMPSON´s Index
dbh	Diameter at Breast Height (cm)
d_q	Quadratic Mean Diameter (cm)
FAO	Food and Agriculture Organisation of the United Nations
FE	Forest Enterprise
FMB	Forestry Management Board
G	Basal area (m^2)
Glk.	Coefficient of parallel variation (*Gleichläufigkeit)*
H´	SHANNON diversity Index
h	Height (m)
ha	Hectare
IVI	Importance Value Index
IUFRO	International Union of Forestry Research Organisations
Ks	Coefficient of Similarity based on species occurrence
K_G	Coefficient of Similarity based on basal area
MAI	Mean Annual Increment (m^3)
MHD	Minimum Harvestable Diameter
N	Number of trees per hectare
R	Coefficient of Determination
TSAP	Time Series Analysis and Presentation
v_l	Logged volume of stand
v_{po}	Volume of potential timber trees in the stand
v_t	Stand volume

1. Introduction

1.1 Classification of riparian landscapes

Riparian areas are defined as "transitional areas between terrestrial and aquatic ecosystems and are distinguished by gradients in biophysical conditions, ecological processes, and biota. They are areas through which surface and subsurface hydrology connect water bodies with their adjacent uplands. They include those portions of terrestrial ecosystems that significantly influence exchanges of energy and matter with aquatic ecosystems. Riparian areas are adjacent to perennial, intermittent, and ephemeral streams, lakes, and estuarine shorelines" (cit. ANONYMOUS 2002).

In terms of the forest vegetation occurring adjacent to watercourses, riparian forests are described as the generally narrow patches of woody species vegetation running along edges of watercourses and banks of lakes (LAMPRECHT 1989). There are several terms, have been used to designate this forest formation which include: Gallery forests (LAMPRECHT 1989, BRAGG et al. 1993, KELLMAN et al. 1994, FELFILI 1995, SCHEUBER et al. 1996, BARBOSA 1997), riverine forests (SCOTT 1989, BRINSON 1990, MEDLEY 1992, NATTA 2003) and riparian forests (RICHTER 1998, QUINN et al. 2004). In South America, based on its relationship with the watercourses, this forest formation is called: "ciliary forests", as around sluggish rivers in the centre-west region they occur on more elevated ground, in the southern part of Brazil "cerrados" dominate and this term is extended to include the forest formation that borders the rivers and streams. Other names that are used as well are juxta-fluvial, marginal, hygrophilous and river-bordering forests. They are named "condensation forests", when they occur in deep valleys (BARBOSA 1997). In the context of the current study, the term "riparian forest" is used.

Riparian landscape can be distinguished from their surrounding environments based on the geomorphology, river process and hydrological regime as well as the riparian vegetation communities as shown in table 1.1.

Table 1. 1 Overview of riparian landscapes

Classification	Criteria	Author
Fringing floodplain Internal delta Coastal deltaic floodplain	• Processes of erosion and deposition. • Form of riparian lands-capes.	WELCOMME (1979)
Small channels Intermediate channels Large channels	• River bed material size. • Characteristics of river channel (gradient and depth).	CHURCH (1992)
Forested landscapes with deep, well drained soils Forested landscapes with shallow soils Arid and semiarid landscapes	• Hill-slope runoff of water to riparian areas. • Topography and hydraulic properties of sediment. • Regional climate condition.	ANONYMOUS (2002)
Permanently flooded Periodically flooded	• Hydro-period • Water quality	PRANCE (1979)

WELCOMME (1979) defined three major types of riparian landscapes: fringing, which are the linear riparian corridors, internal deltas, where topographic plains may flood from a combination of precipitation and over-bank flow from the river, and the coastal deltaic floodplains. The extensive floodplains were mapped along the Paraná and Amazon Rivers in South America. Africa consists of many rivers, both delta and fringing floodplains. The Asian rivers such as the Sundabarans and Mekong are well known for their extensive deltas. The riparian landscapes along their length, however, have so far been little researched.

NAIMAN and DECAMPS (1997) stated that the ecological diversity of riparian zones is related to variable flood regimes, geographically unique channel processes, altitudinal climate shifts, and upland influences on the fluvial corridor. Depending on the erosional force exerted by river flow and the strength or resistance against erosion of the material forming the bed and the banks, a river has the ability to modify the morphorlogical characteristics of its channel (ROBERT 2003). A process-based classification of rivers, in which bed material size, channel gradient and channel depth are involved was established by CHURCH (1992). According to this classification, three categories of stream channels can be defined based on the ratio of flow depth (*d*) to a grain size index (*D*) (see table 1.2). The flow depth used in this classification is regarded as an average value corresponding to the mean annual discharge. The grain size index is usually taken as the median size of the bed material.

Table 1.2 River channel classification and characteristics (based on ROBERT (2003)), where *d* is flow depth and *D* is grain size index.

Categories	Characteristics
Small channels	• $d/D < 1$ • Bed is arranged in a sequence of steps and pools or cascades. • The morphology is locally controlled by the exposed bedrock. • Shallow headwater segment
Intermediate channels	• $1 < d/D < 10$ • Bed particles are fully submerged in the water. • Most rivers are characterized by channel width of up to 20-30 m. • Relatively straight reaches or meandering rivers of sediment accumulation zones. • The riffle-pool sequences often dominate morphology
Large channel	• $d/D > 10$ • Channel width of 20-30 m, with a corresponding bank-full discharge of 30-50 m^3/s • Well-developed floodplain often dominated by sandy bed material. • Relatively large bed-forms, e.g. dunes

FORMAN and GODRON (1986) emphasised that the general spatial pattern of riparian zones are those of corridors, but patches also appear. In some areas, they may appear to form a network within an overall matrix. They owe their dynamics, structure, and composition to the river process of inundation. In some areas the abundance of water allows the development of broadleaved plants, whereas in others, plant productivity is limited by anaerobic conditions. BRINSON (1990) highlighted the linkages between the river process of inundation, transport of sediments, and the abrasive and erosive forces of water and vegetation dynamics in the riparian zones. When this undulating topography occurs along a transect from stream channel to upland, community types likewise alternate between topographic lows with species adapted to long hydroperiods and topographic highs with species also found in mesic uplands. From its mouth, a river valley may be aggrading, degrading, or maintaining a steady state. The downstream movement transports of alluvium from upstream, which leads to topographic features of fluvial origin. According to BRINSON (loc. cit.), the four factors that play major roles in influencing species composition are hydroperiod, climate, salinity, and biogeographic location. Corresponding changes in species composition would be expected. At the wet end, anaerobic soils, deep water, and strong currents conditions limit species richness and forest development. Only the few species, which are adapted to anaerobic conditions and frequent disturbance, survive. In contrast, a phreatophytic habit is necessary for survival of forest species in floodplains in arid climates, where the supplementary water from the river is absent. In floodplain of arid regions, plants that can tolerate periods of drought by extending roots to the water table and also withstand flooding are most likely to survive. In humid climates, water limitation in riverine forests is seldom experienced and adaptation for water excess becomes important for survival in areas with long hydroperiod.

Based on hillslope runoff of water to riparian areas, topographic and hydraulic properties of sediments, ANONYMOUS (2002) divided forested riparian landscapes into three types (see table 1.1). Humid forested landscapes with deep permeable soils have deep percolation and groundwater flow to riparian areas, in addition to shallow flow on the lower hillslope during intense storms. In areas where local geology includes a soil layer with low permeability, drainage is often restricted to shallow permeable soil. In arid areas, intense precipitation onto hillslopes with sparse xerophytic vegetation and impervious soils creates a situation where overland flow is often the dominant pathway of drainage.

In South America, IRMLER (1977) distinguished between “várzea”, which is forest flooded by white water rivers and “igapó”, which is forest flooded by clearwater and black water rivers. Based on hydroperiods and water type, PRANCE (1979) delineated the following types of inundation forest in the Amazonia as follow:

Permanently flooded:

1. White water swamp forest
2. Permanent igapó (riparian forest)

Periodically flooded:

3. Floodplain forest
4. Seasonal igapó
5. Mangrove
6. Seasonal várzea (with or without associated grassland)
7. Tidal várzea

Inside tropical rain forest areas, MALANSON (1993) noted three major features of the riparian landscape. First, the location of floodplain sites within the basin determines in part the differing hydroperiods and water chemistry of flood flows. Second, the development of floodplain sites and the diversity, assemblages, and species dynamics are related to the geomorphological dynamics of these major alluvial rivers. Third, the connectivity of floodplains sites, especially through specialized means of seed dispersal, is a notable feature of the landscape structure of tropical riparian habitats. DOUGLAS (1999) stated that SE Asia differs from the main tropical rain forest areas of the Amazon and Congo basins, because it has great geological diversity, with the island arcs of active tectonism and volcanicity, whereas the Amazon and Congo occupy sedimentary basins on ancient Gondwana shield rocks.

1.2 Importance of riparian forests

In terms of landscape, riparian forests have been identified as potentially serving a keystone role. Besides providing forest products, this azonal forest formation is an important habitat for fauna and has a very special function in controlling supply and quality of water, as well as protecting the watercourses from erosion (LAMPRECHT 1989, BARBOSA 1997, KELLMAN et al. 1998).

Riparian forests influence environmental conditions in both stream and terrestrial ecosystems. For example, riparian vegetation can buffer changes in stream shade and resulting changes in water temperatures which occur where the forested catchments is logged or changed to pastoral land use. Riparian forest vegetation also moderates air temperatures in riparian areas, which are habitat for a variety of organisms including the heat-sensitive adult terrestrial phases of aquatic insects (MELEASON and QUINN 2004). The ecological function of riparian forests and the associated streams are profoundly interlaced. Riparian forests provide shade that moderates stream temperature, stabilize the stream channel, buffer against soil erosion and contaminants, supply organic matter as an energy source for aquatic biota, and contribute instream wood important for habitat complexity. The fluvial processes of the stream, natural disturbances, and the survival strategies of the trees and thus define the structure, composition, and function of riparian forests (BARBER and RINGOLD 2002).

In watershed regions, the existence of riparian forests in the riparian zones serves as basic condition for assuring the maintenance of the integrity of hydrological processes. They have a function as buffer zones in controlling water supply and erosion (BARBOSA 1997). Riparian forests play an important role in preserving the watershed, such as: controlling rainwater flow, lessening flooding peaks, dissipating energy flowing on the surface, conserving river margins and banks, maintaining thermal equilibrium of the water, nutrient cycling, and sedimentation control. Without forest cover, soils in the riparian areas would be drastically reduced in their capacity to retain rain or irrigation water. Instead of infiltrating into the soil the water flows over the surface, forming torrents, which prevent the adequate renewal of ground water and reduce stored water. The removed soil will, in turn, accumulate in lower grounds gradually causing the silting up of watercourses (LAMPRECHT 1989, BARSOSA 1997).

Vietnam possesses a great diversity of wetland habitats including large estuarine and delta systems with many freshwater lakes, water-storage reservoirs, and numerous rivers and streams (SCOTT 1989). The geographical characteristics result in uneven spread of runoff and uneven geographic spread of surface water in Vietnam (ANONYMOUS 2005). Thus, more than the other vegetation types, the forested wetlands and riparian forests are well-known in this context for their role in controlling water sources, water runoff, flood, drainage and navigation improvement for the basin regions, and stream bank erosion.

1.3 Characteristics of riparian forests in the tropics

The formation and development of riparian forests are diversified by the geomorphologic landscape and in the geologic characteristics where they occur. It is possible to find variations in the type of riparian forest along the extension of the stream (SCHIAVINI 1997) (see fig. 1.1). The riparian forests are part of an ecosystem controlled by special conditions and related to microclimate, soil fertility, and ground water fluctuations, thus containing particularly adapted forest communities.

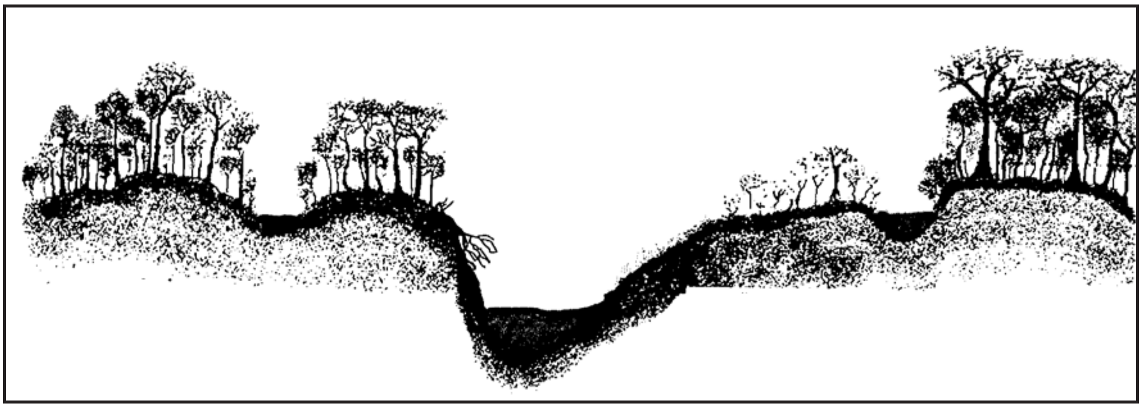

Fig. 1.1 Possible occurrence of vegetation next to water courses on different topography (BARBOSA 1997, SCHÖNGART 2003).

Comprised of evergreen and moist deciduous forest types, riparian forests have often been shown to display high-structural and compositional diversity. The pattern of vegetation most often observed in riparian forests is that species composition changes along a gradient of flooding frequency, as result of the responses of species to flooding and factors associated with soil aeration (BRINSON 1990). Due to the flood-duration component of hydroperiods, flood-tolerant species tend to be more prevalent on floodplain of large rivers than small ones. Several authors have reported the lower density and reduced species numbers in the understory of this forest formation, particularly in the wettest portions of floodplains.

In other riparian forests, trees densities are higher and shrubs are quite dense and prickly. Another important characteristic of riparian natural forest species is the low number of individuals per area and highly fragmented forest strips, which lead to a great diversity of trees. Thus, in order to describe the riparian forest strips completely, the inventory methods developed for these forests have to be specified and well adapted (LUND 1997). In addition, because many plants may be succulent, they may be more sensitive to changes in the climate. Therefore, seasonality needs to be considered and more frequent measurement is required in the inventory.

1.4 Research on riparian forests

Understanding the patterns of riparian forest composition and structure is important because the mix of trees and their positioning on geomorphic landforms reflects, in part, ecological processes. However, the forested riparian areas and riparian forests, especially in the tropics have been little studied so far (IMANA et al. 1997, RICHTER 1998).

MALANSON (1993) described the riparian landscapes, through examining the ecological systems of streamside and floodplain areas from the perspective of landscape ecology. In his work, the specific spatial pattern of riparian vegetation was seen as a result of the ecological, geomorphological and hydrological processes that appear along rivers. The role of the riparian zones in controlling species distribution and abundance as well as the broad processes, which operate inside these landscapes, were discussed and reviewed. Furthermore, the landscape structures of global riparian zones, including the arid and semi-arid gallery forest, tropical forest, subtropical floodplain forest, humid broadleaf forest, forest-grassland transition and grasslands, mountains, as well as taiga and tundra ecosystems were compared. It was concluded that riparian structures are controlled by the spatial dynamics of channels, soil moisture, flooding, and human impact. These dynamics are a part of integrated hydraulic structures, the cascades of water, sediments, nutrients and carbon fluxes, and plant dynamics. The potential for linking hydrological, geomorphological and ecological simulation models is also explored and recommended for these valuable resources.

American riparian forests

BRAGG et al. (1993) compared the plant-water relationship between seedlings (1-5 years old) invading tall grass prairie and adult trees of *Quercus macrocarpa* Endl. and *Quercus muehlenbergii* Engelm. (Fagaceae) in adjacent gallery forest. It was shown that in this drought-prone ecosystem, the influence of the plant water potential on *Quercus* survival and growth is greatest during establishment and then after forest development. Older seedlings (more than 4-5 years old), saplings, and isolated trees within the prairie may experience the least water stress due to a reduction in both inter- and intraspecific competition for water. The research data suggest that in the absence of severe fire or drought during the growing season, riparian forest tree species will continue to expand towards the tall grass prairie.

KELLMAN et al. (1994) showed that savanna riparian forests in Belize and Venezuela, support densities of local tree species that are comparable to those of continuous tropical forests of the region and flora characteristic of these forests. Species coexistence in the riparian forest is mediated by a large suite of mechanisms, including occasional occurrence of fire. A forest-edge community of fire-tolerant trees is important in preserving microclimatic stability, but appears to be gradually destroyed when fires become too frequent. The existence of these long-isolated but floristically rich forest patches indicate that the loss of plant biodiversity is not an inevitable consequence of forest fragmentation. It is suggested that riparian forests could have been an important refuge for tropical forest species during Pleistocene aridity, and could play a role similar during future periods of human deforestation.

SCHEUBER et al. (1996) have recommended the survey method for riparian forests based on the results from a project describing the actual situation of riparian forests of the Bananal River in Central Brazil. Dealing with the specific situation of riparian forests and the huge amount of data that had to be assessed in limited time, a transect design with systematic distribution was used for the surveys. It is considered the most appropriate design for surveys focusing on ecological parameters like plant diversity, plant-soil-water relationships and structure gradients in gallery forests of Central Brazil.

The results of a six years study on ca. 64 ha of undisturbed gallery forest in Gama, Central Brazil, showed that the diversity of species and structure seems to be maintained in an undisturbed condition (FELFILI 1995). Leguminosae, Fabaceae, Myrtaceae and Rubiaceae were the families richest in numbers of species. Most individuals and species were below 45 cm dbh and 20 m tall whereas the maximum diameter per species ranged from 30 to 95 cm. The density structure of trees and natural regeneration was similar, with about 80% of the species representing only 1% of the total density. The periodic mean annual diameter increment for trees from 10 cm dbh, was about 0.25 cm/year. The soils were dystrophic with high aluminium content. Multivariate analysis suggested the stream, natural gaps, and edges as the main causes of floristic differentiation at the community level.

SILVA et al. (1996) has found that the direct relationship between topography and groundwater levels was the main determining factor of the Pitoco (Brazil) riparian forest boundaries, structure, and floristic composition. Variations of physical and chemical properties of soil within the forest were correlated with the position on the slope. Processes affecting soil water status changed constantly, affecting boundaries between the vegetation communities. These changes were demonstrated by the presence of cerrado species within the riparian forest. It was concluded that plant communities in the study area were closely associated with slope, drainage, and soil properties.

Synthesizing from various research on the riparian forests, BARBOSA (1997) emphasize the important ecological role of this azonal forest formation in water protection and biodiversity conservation. Furthermore, different developing trends and some models applied to restoration of riparian forests are referred to and discussed in this work.

MEIRA-NETO et al. (1997) investigated the phytosociological aspects of Ponte Nova riparian forest in Central Brazil, a fragment of alluvial moist deciduous tropical forest that was used in actions to mitigate environmental damage caused by construction of the hydroelectric station. The results showed that the Ponte Nova riparian forest presented a singular structure in compared with other riparian forests in Minas Gerais. Fifty-eight species were sampled and the Shannon diversity index calculated. The most important species (in terms of Importance Value Index, IVI) were *Protium heptaphyllum* March. (Burseraceae), *Xylopia sericea* A. St. Hil. (Annonaceae), *Apuleia leiocarpa* Macbride. (Leguminosae), *Byrsonima variabilis* A. Juss. (Malpighiaceae), *Tapirira guianensis* Aubl. (Anacardiaceae) and *Hirtella hebeclada* Moric. (Chrysobalanaceae). Based on the study results, seedling production and afforestation activities were suggested properly for the area in order to reduce environmental damage resulting from installation of the hydroelectric station.

Based on historical records of burning, field observations, and a manipulation experiment, KELLMAN and MEAVE (1997) evaluated the extent and impact of fire in a system of riparian forests in the Mountain Pine Ridge savanna, Belize. The outer boundaries of riparian forests are fire-prone zones, but fires rarely intrude into these forests. It was concluded that the riparian forests contained core zones into which fire very rarely intruded, and peripheral zones that experienced fire incursions that were patchily distributed in space and time. In the latter zones fire incursions played a role comparable to that of canopy gaps in continuous forests, but also created a unique class of micro-habitats to which a subset of tree species was specialized. The fire regime over the recent past in this riparian forest system appeared to have had an enriching effect on the forest communities, and such systems represented plausible refugee for forest species in fire-prone landscapes.

Through the study on structure and function of two tropical riparian forest communities, KELLMAN et al. (1998) concluded that the more abundant tree species formed three functional groups along gradients between streams and forest edges: edge-concentrators, core-concentrators and generalists. Soil fertility, tree growth, and recruitment showed no consistent increase close to streams. In contrast, forest edge zones exhibited increased rates of tree growth and recruitment. This indicated that growth processes in these forests were light-limited rather than soil-limited. Generally the forest edge zones are favourable habitats for tree populations, especially for fire-insensitive tree species.

BIDDULPH and KELLMANN (1998) investigated the factors contributing to the resistance of riparian forests within savannas to the entry of fire, using field observations and manipulation experiments during 1994-1995 along a stream located near Kavanayen in the northern part of the Gran Sabana, Venezuela. The forest varied in width from 100 m to several hundred metres, and was surrounded by treeless savanna, with well-defined forest/savanna boundaries. The mass of savanna fuels did not decrease close to forest boundaries, and in some instances increased. Savanna fuels adjacent to forests were more moist than in the savanna beyond for only one day after rainfall. A fuel drying experiment conducted in both forest and savanna microclimates indicated that both fuel type and microclimate contributed to the resistance of forests to fire entry, although the former played a larger role. While savanna fuels in a savanna microclimate became ignitable approximately one day after rain, forest fuels in a forest microclimate required 4 weeks to achieve ignitability. A further experiment juxtaposing forest fuels to burning savanna indicated that fire entry into forests was facilitated by deep root mats and the presence of a superficial litter layer, both of which become attenuated at the forest/savanna contact. It was concluded that fuels in these forests could reach an ignitable state late in the dry season, but that frequent fire entry was probably precluded by the tendency of savanna fires to occur earlier in the dry season and by discontinuities in fuel at the savanna/forest borders.

SMITH et al. (1998) presented a case study conducted along the lower Colorado River (in Arizona) and the lower Virgin River floodplain (Nevada), USA, in which the water relations, transpiration and overall functional ecology of *Tamarix ramosissima* Karel. ex Boiss (Tamaricaceae) were compared with the native taxa it replaced. The paper was concluded with an applied perspective which focused on how the diversion of rivers in the West may influence the water relations of riparian plants, and thus potentially impact riparian vegetation as a whole. Recent water-relations research that tracks water sources of riparian plants using the stable isotopes of water indicated that many plants of the riparian zone use groundwater rather than stream water, and that not all riparian plants were dependent on groundwater as a moisture source but may occasionally be dependent on unsaturated soil moisture sources. *T. ramosissima* exhibited leaf-level transpiration rates that were comparable to native species, whereas sap-flow rates per unit sapwood area were higher than in natives, indicating that *T. ramosissima* could maintain higher leaf area compared with native taxa, due to its greater water stress tolerance. *T. ramosissima* invasion led to desiccation and salinization of floodplains, due to its salt exudation and high transpiration rates, and might also accelerate fire cycles, thus pre-disposing these ecosystems to further loss of native taxa. It was suggested that riparian species on regulated rivers might be exposed to seasonal water stress due to depression of floodplain water tables and elimination of annual floods, and a community shift toward more stress-tolerant taxa, such as *T. ramosissima*, could potentially be occurrenced.

The phenology of a cerrado and a riparian forest community were compared with respect to rainfall from January 1996 to January 1997, at the Água Limpa Farm in the Cerrado Biosphere Reserve in Brasilia-Distrito Federal, Brazil (GOUVEIA and FELFILI 1999). All individuals from 3 cm dbh in a 10 x 100 m strip in the cerrado *sensu stricto* were monitored, as well as those from 5 cm dbh in a similar sized strip in the Gama gallery forest. Flowering, fruiting, and leaf changes were monitored quarterly over the 13 months. Most of the cerrado species flowered during the dry season but the maturation of the fruits occurred more evenly during the year. However, the most abundant species flowered during the rainy season and their fruits matured from the end of the dry season until the beginning of the rainy season. Both flowering and fruiting in the gallery forest occurred more evenly during the year, but the most abundant species flowered and their fruits matured during the dry season, although both communities were evergreen.

GODOY et al. (1999) compared the non-deltaic, riparian-flooded forests of the Orinoco and Amazon River basins. The author identified ecological relationships between these forests and their environments, which could be useful in establishing schemes for biodiversity conservation. Adaptations of species to flow seasonality, flooding intensity, sedimentation pattern, and nutrient depletion are described. The floristic analysis has produced a preliminary list of 242 tree species common to the riparian-flooded forests of both basins. This relatively high number of species is related to connectivity between the riparian corridors of both basins and the effective operation of dispersal mechanisms. Highly oligotrophic environments add uniqueness at the regional scale through the evolution of endemic species presenting adaptations not only to flooding but also to nutrient depletion. The process of genetic diversification and the evolution of genotypes adapted to flooding are suggested to explain longitudinal gradients at tributary junctions and floodplain-upland ecotones where current fluvial dynamics are unpredictable over ecological time scales.

GODOY et al. (2001) investigated the distribution of woody species along different ecological gradients within the riparian forests of the lower Caura River, Venezuela. A Multiple discriminant analysis resulted in a function including depth of inundation, ratio of alkaline/alkaline earth major cations, and soil phosphorous content, which accounted for 83% of the variance between the four groups. Inundation level and phosphorous content were the most significant variables in the ordination, within which the first two axes explained 48% of the species-environment relationships. Tree density, species richness, and diversity are shown to change significantly along the lower Caura with highest values associated with levees in sectors upstream of the La Mura Rapids; effects of terrestrialization and intermediate disturbance are proposed to explain these patterns. Floristic elements typical of both Amazonian Igapó and Várzea forests are shown to occur along the whole riparian corridor of the lower Caura, but the majority occur downstream of La Mura Rapids. The intermediate nutritional status of the Caura River and a hydroecological confluence effect associated with higher flooding depths and stronger biogeochemical gradients along the lower reach are suggested to explain the occurrence of Igapó and Várzea species.

Riparian vegetation and stream condition in three adjacent watersheds in SE Puerto Rico were investigated by HEARTSILL-SCALEYY and AIDE (2003). They indicated that changes in land cover from forest to agriculture often alter riparian vegetation, which modifies the physical properties of streams. Understory vegetation in the forest sites was mainly shrubs, herbs, and ferns, whereas the mixed and pasture sites were dominated by grasses, vines, and bare soil. *Syzygium jambos* (L.) Alston (Myrtaceae), *Spathodea campanulata* P. Beauv. (Bignoniaceae) and *Guarea guidonia* (L.) Sleumer. (Meliaceae) were the most common tree species in the riparian areas. A positive relationship was found between tree cover and percentage of dissolved oxygen, and a negative relationship was found between tree cover and percentage of substrata covered by sediments from eroded soil. The amount of woody debris in the streams tended to increase with forest cover.

African riparian forests

Results of research on structure, composition and management of vegetation along the Niger River in Mali show that the riparian forest was of moderate density apart from the immediate riverbank. Upper storey species reached a height of 10-15 m, very rarely 20 m (ZOUNGRANA and TEMU 1997) Five species: *Syzygium sp.* Gaertn. (Myrtaceae), *Pterocarpus santalinoides* L´Hér. ex DC. (Leguminosae), *Mitragyna inermis* (Willd.) K. Schum. (Rubiaceae), *Mimosa pigra* L. (Mimosacae), and *Ficus gnaphalocarpa* Steud. ex Miq. (Moraceae) were basically linked to the gallery forests and constituted a continuum across different ecozones. The diversity of species is quite low compared to the open savannah woodland. Directly after the riparian forest strip followed the overgrazed, transitional woodland, in which the vegetation was degraded, trees were scattered emerging from dense shrubby species and had the height of 8-10 m. In many places, this area was converted into sorghum and millet fields.

HOVESTADT et al. (1999) observed the seed dispersal mechanisms and the vegetation of forest islands by the woody plant species in 18 savannas and 3 riparian forest plots in Comoé National Park, Ivory Coast. It was concluded that the transition zone between forest and savanna was typically characterized by a dynamic patchwork. The riparian forest was dominated by *Cynometra megalophylla* Harms (Caesalpiniaceae). Disturbed forests harboured more savanna species but also a distinct group of disturbance-tolerant species. The latter showed an exceptionally high fraction of animal dispersed plant species (80 %) compared to other less tolerant forest species, while wind dispersed species or species lacking long distance seed dispersal mechanisms were correspondingly rare. It was concluded that species composition of forest islands is to some extent determined by the seed dispersal abilities of the different species.

Woody plants in the last existing fragment of closed gallery forest in the Delta du Saloum National Park, Senegal, were investigated using of a 0.6 ha transect covering the main part of the riparian forest (LYKKE and GOUDIABY 1999). There were 24 species and 369 individuals $\geq$ 5 cm dbh with a basal area of 12.6 m^2, 1062 individuals $\geq$ 1 cm dbh in 31 species, and 1730 individuals <1 cm dbh in 29 species. Constrained clustering revealed six floristically distinct sections along the transects, and these sections coincided with structural differences. The vegetation in the study area is marked by degradation caused by frequent and intense fires coming from the surrounding savanna and favoured by declining precipitation. However, the riparian forest is unique to the area and of crucial importance for conserving biodiversity. It could be potentially used in the future as a resource-base for restoration of the riparian forest system by means of natural regeneration.

Australian riparian forests

FRANKLIN and BOWMAN (2004) carried out research on the environmental edaphic and historical factors influencing the patchy distribution of *Bambusa arnhemica* F. Muell. (Poaceae) at catchments and streambanks in the NW of the Northern Territory of Australia. The result showed that *Bambusa arnhemica* occurred predominantly in gallery forests on flood-prone but nevertheless well-drained and deep alluvial soils on sloping stream banks. It ranged widely along lentic watercourses, from ephemeral headwater streams to the banks of major rivers and levees on the coastal floodplain. This species did not occur in savannas, savannas adjacent to *B. arnhemica* gallery forests were also flood-prone and on deep alluvial soils but were upslope on level ground. *Bambusa arnhemica*'s infrequent non-riparian occurrences were on a wide variety of substrates but generally on soils of moderate fertility and in coastal and/or rocky areas where at least partial topographic protection from fire is likely. Within and between catchments, the distribution of *B. arnhemica* was broad, occurrence being almost always with continuous occurrences downstream from highly variable 'starting' points to the poorly drained coastal floodplain. At the local scale, *B. arnhemica* appears constrained by poor drainage and high fire-frequencies. Enhanced soil fertility may increase its capacity to cope with fire. At the catchments and on a global scale, the distribution of *B. arnhemica* was proposed to be the product of infrequent and as yet incomplete dispersal across and away from watercourses by seeds that lack specialized dispersal mechanisms, combined with passive dispersal along streams.

QUINN et al. (2004) researched the influences of riparian forest type and logging on forest stream invertebrate communities, with or without native forest riparian buffers at 28 stream sites on Coromandel Peninsula, New Zealand. Research results showed that clearcut reaches differed in invertebrate community structure from pine and native forested reaches, and from logged reaches with continuous riparian buffers. Clearcut reaches had lowest diversity, taxon richness, relative abundance and numbers of the sensitive mayfly, stonefly and caddis fly taxa, and index of biotic integrity. In contrast, sites that had been logged leaving continuous buffers did not differ from those with intact native or mature plantation forest, indicating that buffers greatly reduced disturbance associated with logging. Correlation and multiple regression analyses showed that logging impacts are strongly related to increases in periphyton biomass and water temperature associated with changes in stream lighting and increased channel instability with sedimentation.

Asian riparian forests

RICHTER (1998) concluded from the research on riparian forests in East Kalimantan, Indonesia that the forest formation depended mainly on the river dynamics. The flooding period within the tree´s rhizosphere was used to categorize tree species into five different flooding tolerance classes. Longer flooding times are associated with a decreasing species diversity and an increasing the number of trees ≥ 10 cm dbh per hectare.

1.5 State of natural riparian forests in North-eastern Vietnam

Riparian forests in Vietnam usually occur on narrow slopes along rivers, where *Cynometra* L. (Leguminosae), *Crudia* sp. Schreb. (Leguminosae), *Crataeva* L. (Capparaceae), *Dipterocarpus alatus* Roxb. (Dipterocaparceae), *Hopea odorata* Roxb. (Dipterocaparceae), *Hydnocarpus* Gaertn. (Flacourtiaceae), *Nauclea* sp. Korth. (Rubiaceae), *Eugenia fluviatilis* Hemsl. ex Forb. & Hemsl. (Myrtaceae) and *Telectadium* Baill. (Asclepiadaceae) are common (FAO 1999).

For a long time, natural riparian forests in NE Vietnam have been subject to human disturbances in which tree harvesting and exploiting are common. In spite of the important ecological role of water protection as shelter for associated fauna, in biodiversity conservation, and in the prevention of erosive processes for the region, riparian forests are continuously degraded by anthropogenic activities. Many forested areas were overexploited and are being threatened. This has occurred through illegal exploitation by farmers and other interest groups in extending agricultural areas, selective logging of timbers, extensive extraction of fuel-wood, bamboos as well as collection of raisins and other non-timber forest products. This has resulted in fragmented, degraded, and narrow riparian forest strips. The number of valuable tree species has been reduced drastically. Consequently, along most of the big rivers in the NE, riparian forests do not exist any more. The remaining forests still occur now along branch rivers or streams of overexploited forests or bamboo mixed forests. The unfavourable conditions led to the decrease of plant and animal species as more of the protection function of these forests were reduced.

In recent years, flash floods, droughts, typhoons, and other natural catastrophes have frequently occurred here as a result of the uneven geographical characteristics, tropical climate and land clearing in the watershed areas. Recognizing the ecological importance of riparian forests, the Vietnamese Government is now making great efforts towards forest recovery, especially in riparian and watershed areas. Besides selecting and establishing different protected areas, various national and international projects focusing on re-vegetating, restoring and reforesting forests are being carried out. Due to their key ecological attributes and role, understanding the status of riparian forests is paramount to the management and protection of these forests. Nevertheless, the ecosystems of the forests in the watershed areas, especially the riparian forests are still poorly known and only little research exists. The literature descriptions on riparian vegetation applicable to NE Vietnam provide general insights in plant composition and structure (ie. bamboo communities), but are often limited in detailed analyses of specific forest communities, management practices, or area descriptions.

1.6 Research objectives

Two natural secondary riparian forests in Son Dong district, NE Vietnam were investigated. The overall objective of this research is to contribute to a better knowledge of structure, dynamics, and ecology of riparian forests in NE Vietnam. Beside analysis of vegetation composition, structure, and dynamics of the riparian forests, plant responses to the specific environment are of special interests. The specific objectives are to:

1) Analyse the local knowledge of the riparian forest areas, forest functions and of useful forest plants and their uses, as this knowledge can impact on the status and management, and utilization of these areas
2) Investigate the tree species composition and stand structure in two riparian forests.
3) Identify the potentials of the stands in species richness, stand dynamics, and productivity.
4) Assess the inventory methodology which is specifically applied in these riparian forest formations.
5) Compare the changes in stand structure and vegetation dynamics along different gradients within the study areas to identify the characteristics of these forest formations.
6) Analyse the tree-environment relationships in order to identify a possible recolonising and spreading capacity of these species.

2. Site description

2.1 Geography, topography and hydrology

The study sites are situated in the Son Dong, a mountainous district located in the NE of Bac Giang province (20°17'-21°21' N, 106°02'–107°23' E) that belongs to the Watershed area of Luc Nam River, NE Vietnam. In the North the district is bordered by the Lang Son province, on the West by the districts Luc Ngan and Luc Nam and on the S and E by Quang Ninh province (fig. 2.1). With a total land area of 84,432 ha, Son Dong has almost 46,000 ha classified as forest land. Nevertheless, only 40.3 % of the total land area is still covered by forest (ANONYMOUS 1997).

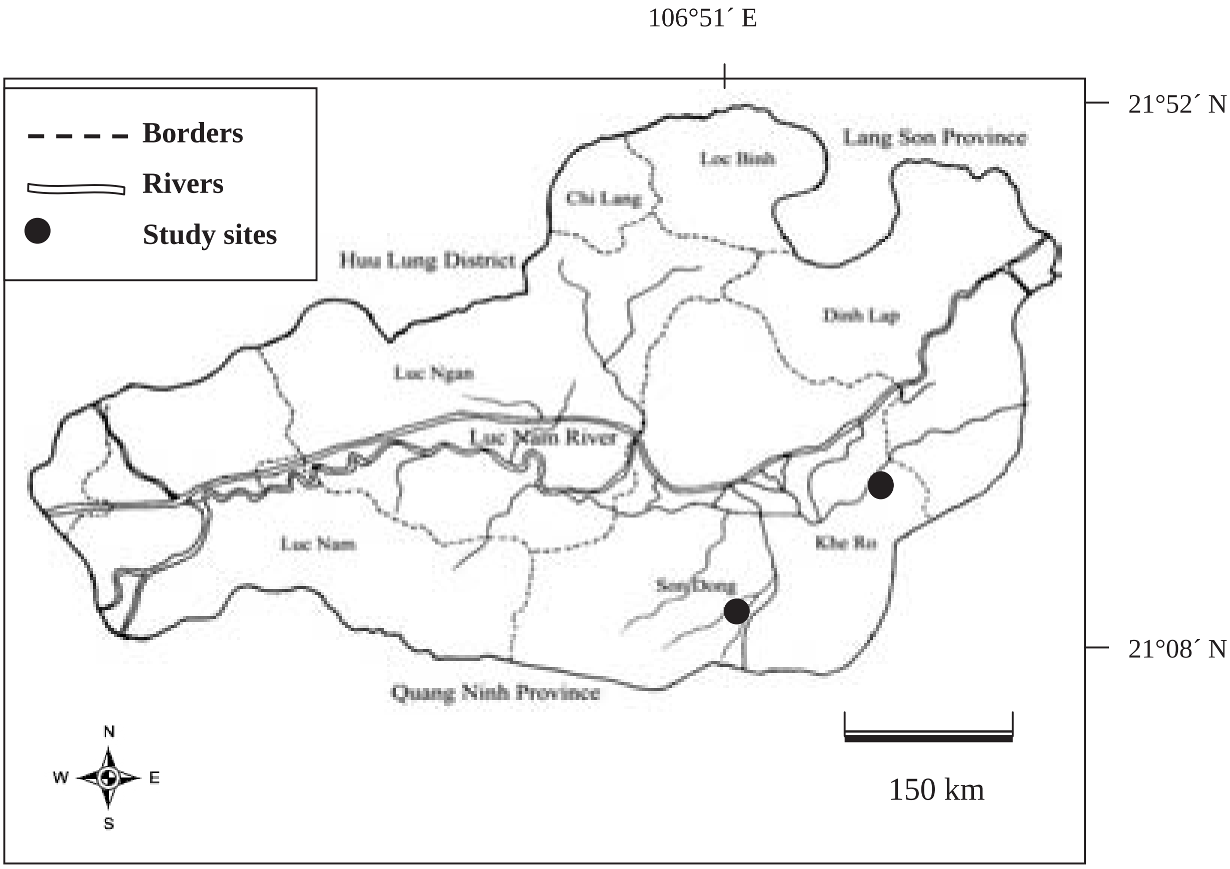

Fig. 2.1 Study sites in the protected watershed area of Luc-Nam River, Bac Giang Province, NE Vietnam (ANONYMOUS 1995).

The topography of Son Dong is mainly mountainous and hilly. It varies from average hill sites to steep mountain slopes with ridge tops reaching elevations of 1,068 m. The average slope is less than 30°, but the SW is composed of stone massifs. Because of this difficult access, the forest here is still preserved in a good state (ANONYMOUS 2002a).

As part of the watershed area of the Luc Nam River, Son Dong has five branch rivers that flow into Luc Nam River. The ragged topography of Son Dong consequences a thick net of small rivers and streams with narrow beds and uneven flow and distribution (ANONYMOUS 2002a). In recent years, combined with deforestation in the watershed areas, flash floods in the rainy season and droughts in the dry season have frequently occurred here. According to long time observations at the Meteorological Station Cam Dan in the central Son Dong district, the average water flow in the Luc Nam River is 11.5 m^3/s, in the flooding season it can reach a maximum of 2400 m^3/s (ANONYMOUS 2002a).

2.2 Climate and soil

The climate of Son Dong is characterised by monsoon influence with two distinct seasons. The rainy season lasts from March to October. The dry season lasts from November to February with average precipitation less than 60 mm per month. Based on climate data that were obtained from the Son Dong Meteorological station with the observation period from 1961 to 2002 (fig. 2.2), the mean annual precipitation is 1,663 mm, with seasonal distribution. Monthly precipitation varies between 15.8 mm in January and 327 mm in August. The mean annual temperature is 22.7°C, reaching maximum of 28.2°C in July (table 2.1) (ANONYMOUS 2002a). There are three monsoon seasons, namely the NE winter monsoon, and the SE and W summer monsoons. In winter, frost occurs frequently.

Table 2.1 Monthly precipitation, temperature, and aridity index according to DE MARTONNE of Son Dong, NE Vietnam (unpublished records of the Cam Dan Gauging station)

Month	**Precipitation (mm)**	**Temperature (°C)**	**Aridity index**
January	16	15.6	7
February	17	16.8	8
March	156	19.8	63
April	105	23.8	30
May	139	26.9	45
June	235	28.0	74
July	214	28.2	67
August	327	28.1	103
September	175	25.5	59
October	105	23.5	38
November	28	19.7	11
December	18	16.6	8

In order to categorise the dry months, the aridity index of DE MARTONNE was calculated for the study area (vide WEIDELT 1999) using the following formula:

$$A_m = \frac{12.n}{T_m + 10}$$

where A_m monthly aridity index,

n mean monthly rainfall in mm,

T_m mean monthly temperature in °C

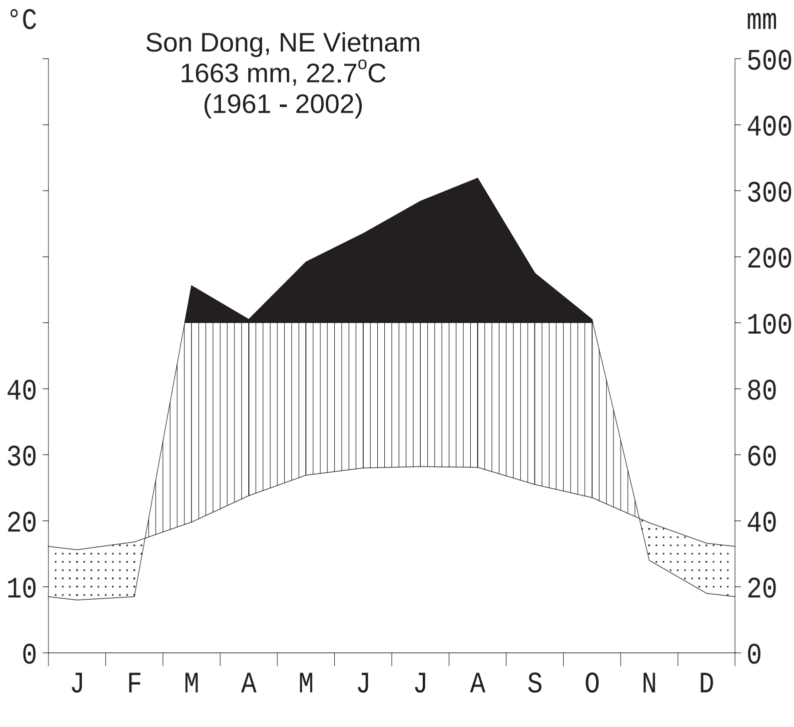

Fig. 2.2 Climate diagram of Son Dong, NE Vietnam (according to WALTHER and LIETH 1967)

As shown in table 2.1 and figure 2.2, in the study areas, four months can be categorised as dry months with aridity index of $\leq$ 20 or rainfall curve below temperature curve.

The Son Dong district is mainly covered by yellowish-red acid soils (Ferralsols or Acrisols according to FAO classification (1973). The soil developed on sandstones has a coarse particle size, very poor water holding capacity, and low fertility. Soils developed on clay schist contain predominantly fine particles and show relatively high fertility (ANONYMOUS 1997).

2.3 Forest vegetation

Within the tropical moist evergreen forest formation, THAI (1999) categorized the forest vegetation of Son Dong into two main forests types (THAI 1999 and ANONYMOUS 1997):

1. Moist tropical evergreen closed forests on low mountain (Lowland moist evergreen forests according to LAMPRECHT (1989)): generally found at an elevation below 700 m asl.. It is a multi-storey forest type, which is dominated by *Erythrophloeum fordii* Oliver (Caesalpiniaceae), *Canarium album* Raeusch (Burseraseae), *Castanopsis indica* A.DC. (Fagaceae), *Madhuca pasquieri* H.Lec. (Sapotaceae), *Vatica tonkinensis* A. Chev. (Dipterocarpaceae), *Mischocarpus oppositifolius* (Lour.) Merr. (Sapindaceae), *Pygeum arboreum* Endl. (Rosaceae), bamboos etc.

2. Subtropical evergreen mixed conifer-broadleaved closed forests on low mountain (Montane moist evergreen forests according to LAMPRECHT (1989)): situated at an elevation above 700 m asl.. This forest type is marked by the abundance of coniferous species like *Podocarpus neriifolius* D. Don (Podocarpaceae), *Forkenia hodginsii* (Dunn) Henry & Thomas (Cupresaceae), *Nageia fleuryi* (Hickel) De Laub. (Podocarpaceae) in mixture with broadleaf tree species.

According to ANONYMOUS (1997) 57 families and 236 tree species are to be found in Son Dong. Because of the long history of unsustainable land use and illegal exploitation, the forests were degraded and the quality in the remaining forested areas has significantly declined. As a result, many secondary stages of forests co-exist. These secondary forests are categorised as follow (ANONYMOUS 1997).

1) The secondary forests in poor condition that were formed after shifting cultivation are categorized as IIa and IIb. These forests account for 12 % of the total area and are reserved for regeneration. Trees are often twisted and

low. Fast growth and light tolerant as well as climax tree species like *Aporusa dioica* (Roxb.) Muell-Arg. (Euphorbiaceae), *Wendlandia paniculata* (Roxb.) A. DC. (Rubiaceae), *Cratoxylum polyanthum* Kurz.. (Clusiaceae) etc. dominate in this type of forest. Seedlings of the valuable tree species are to be found here as well, but in small numbers. The average tree height is between 5 and 10 m.

2) The category IIIa1 forests result from selective logging. This forest is considered poor and accounts for 19 % of the total area. However, this forest is still relatively rich in valuable tree species, such as: *Erythrophloeum fordii* Oliver "Ironwood", *Castanopsis indica* A.DC., *Canarium album* Raeusch, with an average dbh of 15-25 cm and tree heights of 10-15 m. It has a regeneration density of 10,000 to 15,000 seedlings per hectare.

3) Category IIIa2 forests are mostly located in the mountain tops or steep topography with difficult access and have so far remained in relatively good condition. This medium forest state accounts for 9 % of forested land. Many valuable tree species, such as *Erythrophloeum fordii* Oliver, *Madhuca pasquieri* H.Lec, *Vatica tonkinensis* A. Chev. i.A. with dbh up to 80 cm and height of 25 m are found here with relative high abundance.

4) The rich forest category (IIIa3) on 675 ha, accounts for only 0.8 % of total area in the district area, concentrated in the An Lac commune. A high commercial timber volume between 120-150 m^3/ha is estimated for this category.

Table 2.2 Forest area and forest categories of Son Dong district, NE Vietnam.

Forest categories	Area		Commercial Timber	
	(ha)	(%)	volume (m^3/ha)	Total (m^3)
Total forest land	84,620	100		
Natural forest	34,169	40.3		
Natural timber forest:	31,761	37.3		
IIa+ IIb	10,092	11.9	9.7	97,883
IIIa1	16,059	18.9	45.3	637,475
IIIa2	7,610	9.0	94.0	714,890
IIIa3	675	0.8	120-150	-
Natural bamboo mixed forest	1,298	1.5		95,426
Bamboo	197	0.2		

Source: Son Dong district committee (ANONYMOUS 1997)

The investigated forest stands, Tuan Dao and Khe Ro, can be classified as secondary riparian evergreen forest of lowland moist evergreen forest category containing many valuable tree species for timber. Many valuable tree species, which are frequently found in these areas, are listed in the red book of endangered species in Vietnam. These species include: *Erythrophloeum fordii*, *Aquilaria crassna*, *Madhuca pasquieri*, and *Vatica tonkinensis*.

2.4 Forest management

Forested land in Son Dong constitutes 34,168 ha. Of this land, 9,782 ha are used for special uses (e.g. for establishing Nature Reserves), 14,741 ha for protection of watersheds, and further 9,645 ha for timber production (ANONYMOUS 1997). Due to the importance level of protection (water, gene, and bio-diversity conservation) and location of the forest areas, the management practises can be practiced by the local households, State Forest Enterprises, or the Forest Management Board. In forest management, a “people centred approach” is gaining increasingly importance.

Table 2.4 Forest areas and the management practices in forested land of Son Dong, NE Vietnam

	Main categories of forest		
	Protection (ha)	Special uses (ha)	Production (ha)
Forest land	14,741	9,782	9,601
- Natural regeneration	3,500	800	2,700
- Rehabilitation	1,600	200	-
- Enrichment	-	-	7,000
- Afforestation	4,400	508	2,323

Source: Bac Giang Province Committee (ANONYMOUS 2002)

Special-use forests: The West Yen Tu Nature Reserve is directly managed by a Forest Management Board (FMB). Management boards have been established for area control. In general they are to be allocated to cooperatives, households and individuals who will be obliged to implement management plans applicable to each forest. One of the major difficulties in the management of these areas is the presence of settlements within reserves. The human populations are expected to increase, with an accompanying increase in the level of shifting cultivation, hunting, and forest exploitation. Therefore, forest protection activities are implemented with the support and cooperation of local authorities and communities. Contracts are made on a long-term basis (usually 50 years) with households and communities in ecological restoration and in implementing administrative buffer zones for reforestation and protection. Households are entitled to collect dead wood for their own use, provided that they do not damage the forest ecosystem.

Protection forests: Luc Nam watershed protected forests are managed by a forest management board and two state forest enterprises: Son Dong I and II. In the strictly protected area the demarcation and management activities are undertaken with the priority of conservation of forests, including preparation of management plans, survey, mapping, and monitoring. The state forest enterprises and forest management board are also responsible for buffer zone development in order to provide for local area needs for fuel wood and other forest products and to support the development or promotion of environmentally compatible employment or income generating activities, which are expected to relieve pressure on protected areas. These authorities make contracts with households, communities, or individuals to protect and regenerate forest. In return, households can collect dead branches and non-timber products from contracted land. Harvesting and use have to be in accordance to the rules of the forest management boards and must be approved by competent authorities, namely local forest officers. Contracted households can farm on their already existing cultivated area, but are not allowed to expand agricultural land into forest areas.

Production forests: In Son Dong, the production forests that are normally situated in buffer zones or outside of the protection area, are being utilised by forest enterprises and local farmers. However, because natural forests were cleared or degraded, during decades of high-impact timber extraction and shifting cultivation, forest exploitation is now limited for a period of 15-20 years to assist forest recovery and rejuvenation. Extraction of timber from natural forests is gradually being reduced as wood from natural forests and replaced by plantation timber. Currently, state forest enterprises are being managed to meet the objectives of both timber production and environmental protection. They have contracted land to organizations, households, or individuals to protect forests located close to communities. Contracted households receive funds for forest protection and are obliged to protect their areas for regeneration. The forestry practises carried out on forested land of Son Dong are shown in the table 2.4.

2.5 Socio- economical situation

Son Dong has a population of 62,136 people, who belong to six main ethnic groups. 94.3 % of the population live on agriculture and forestry. The total agricultural area of the district is 3,387 ha, with a paddy rice area share of 2,065 ha (332 m^2/person) that is completely allocated to the farmers for 5-30 years (ANONYMOUS 1997).

Although local people live mainly by cultivating paddy rice, maize, sweet potato, and cassava, agroforestry activities contribute more and more to household income. Since the new land law of 1993, the denuded and barren land is allocated to the farmers for 30-50 years. Besides forest conservation practices, local farmers have increased their income through social forestry activities, such as: developing forest gardens with multi-function forest tree species and productive fruit plants with highly market prices, such as *Litchi chinensis* Sonn. (Sapindaceae), *Mangifera indica* L. (Anacardiaceae), *Ananas comosus* Merr. (Bromeliaceae), and *Dimocarpus longan* Lour. (Sapindaceae). Practises like forest rehabilitation, reforestation, and agroforestry are being carried out with support of several National and International projects, such as the Vietnamese-German Afforestation Programme, the 5 Million hectare reforestation program (previously called the 327 program), and the Sedentarization programme.

Despite the sedenrarization programme, illegal slash and burn practices in the area are still carried out. Primary schools are built in every commune. Although there are roads for cars through most of the communes, these are in bad conditions and many communes are difficult to access in rainy seasons. Health care stations are established in all communes, but are not yet so effective due to lack of human resources, medicines and instruments (ANONYMOUS 1997).

3. Materials and methods

3.1 Selection of study sites

Focusing on the riparian forest communities and their reaction towards their site conditions, the results of the study are expected to facilitate long-term forest management in this azonal forest formation. Therefore, the following criteria were used to choose the study sites: 1) Areas have to be adjacent to water courses (rivers, streams), 2) The vegetation has to be in a semi-natural state, and 3) The study areas have to represent the differences in the site factors, management practices and human impact. Based on information gathered from villagers, employees of Son Dong forest enterprises, and foresters of Khe Ro FMB as well as field observations, the two following natural secondary riparian forest sites were chosen in Son Dong, NE Vietnam (fig. 3.1):

Fig. 3.1 The researched natural riparian forest stands in Tuan Dao (left) and Khe Ro (right). Son Dong, NE Vietnam

(1) The so-called **Tuan Dao** forest stand lies on Tuan Dao Branch River in the buffer zone of the West Yen Tu Nature Reserve. The river has immediate channel. It is situated in Tuan Dao commune, in the NW of the Son Dong district, with geographical position is 21°19´ N and 106°40´ E. Tuan Dao is about 10 km from the district centre, with an average height of around 200-500 m a.s.l.. The Kinh (Vietnamese), Chinese, Cao Lan, and Tay are the main ethnic groups here. The forest area is easily accessed due to the commune road, which

was built along the river. Previously, the forests here were managed by the national forest enterprise. They have been allocated to local farmers for preservation since 1997. In this area, exploiting activities of timber woods, bamboos and other non-timber forest products are continuously carried out.

(2) The **Khe Ro** site is situated in An Lac commune and has the geographical position of 21°10´N and 106°57´E. This site is difficult to access, especially in the rainy season, because of the stream and river net surrounding the area. The river has a small channel controlled locally by the exposed bedrock. The two streams: Khe Ro and Khe Din, which belong to the headwater streams of Luc Nam river, are main streams flowing through the Nature Reserve. Natural forest including rich forest category (III_{a3}), constitutes for about 1.8 % of the total district forest. In contrast to Tuan Dao, Khe Ro forests belong to the strictly protected watershed area of the Luc Nam river within the West Yen Tu Nature Reserve. The forest protection and conservation activities are undertaken by a Forest Management Board. Since 1991, every type of forest intervention has been strictly forbidden. The Tay village Na O lies directly in the rehabilitation zone of the Reserve and plays an important role in forest conservation and protection practices.

3.2 Data collection

3.2.1 Survey of stand structure and dynamics

With their special geological and topographical characteristics, riparian forests are very sensitive and often protected areas by law. For this reason, the survey method must be very flexible in order to adapt to the various situations, different survey purposes and data demands. Moreover, surveys have to be carried out carefully to avoid the destruction of the forests (SCHEUBER et al. 1996).

The surveys were conducted separately on transects located along the two selected rivers. Based on the homogeneity of the forest population and the precision requirements of the survey, the number of transects represents the minimum representative area. The minimum representative areas were determined by using so called species-area curves, in which the survey were continued until none or very few new tree species with dbh $\geq$ 5 cm were encountered (LAMPRECHT 1989, WEIDELT 2000). In order to reach the minimum representative area, of each study site total area of 1 ha was sampled.

The inventory was conducted on 20 transects along each of the river. Based on a topographic map with scale 1:10,000, a systematic transect design was applied (fig. 3.2). Based on the size and form of the forest area and the desired sampling rate, the distance between transects was set at 150 m. The transects were located so they were perpendicular to the river (SCHEUBER et al. 1996, IMANA 2002).

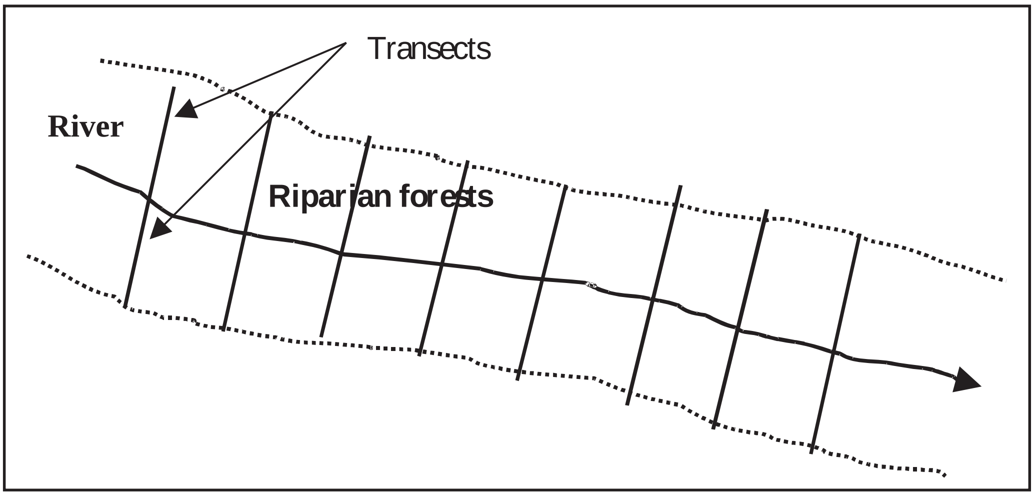

Fig. 3.2 Systematic transect design for riparian forests, Son Dong, NE Vietnam

The transects were located on both sides of the river, starting from the river bank. Each transect was 10 meters wide with 5 meters on each side of the transect's centre line. Based on the width and characteristics of the riparian forest strips and the requirements of the survey, a transect length of 50 m was chosen. The centre line was marked with poles in every 10 meters (fig 3.3).

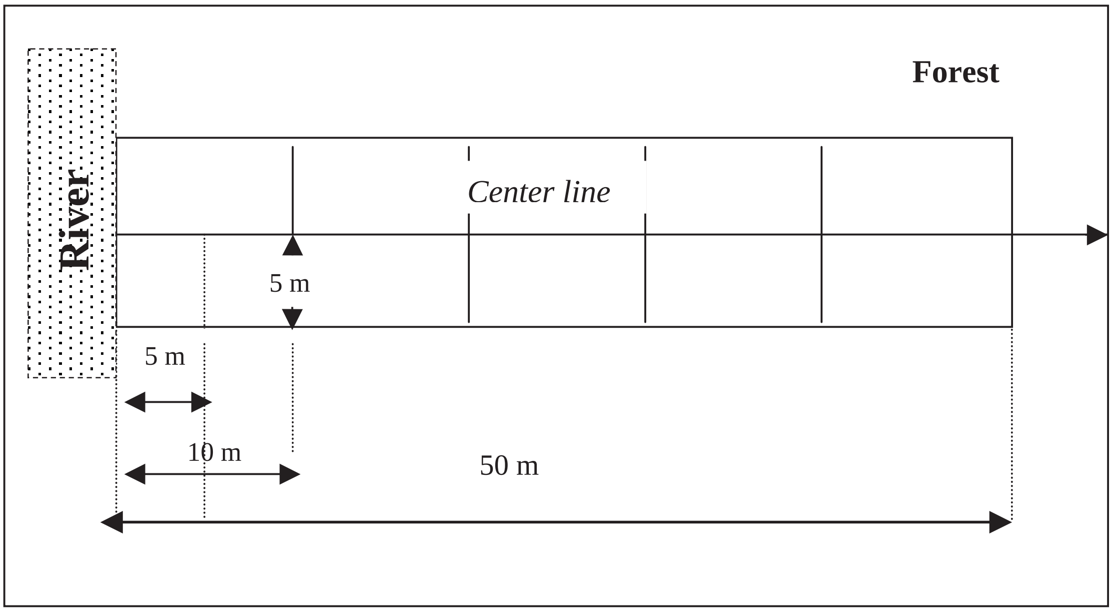

Fig. 3.3 Transect layout and subplots used for the survey of the riparian forests in Tuan Dao and Khe Ro, Son Dong, NE Vietnam.

The following information of the transect layout was recorded:

a) Transect position: Identified on the map, use of compass
b) Transect length: Measured in the forest with fibreglass tape
c) Angle of the transect from river: Use of compass
d) Addition information: Transect status and evidence of past human activities.

Based on field observation and evidence from literature about the stand history, both study areas were considered to be newly rehabilitated stands with young trees dominating. In the transect layout (10 m x 50 m), all trees in the population with dbhs ≥ 5 cm were surveyed, whereby the following silvicultural parameters were focused on:

(1) Tree species: were identified in the field with support of tree finders. Unidentified specimens, including leaves, fruits etc., were identified by a botanist at the Thai Nguyen University, Vietnam.
(2) Position: The positions of all measured trees were noted based on the distance from the centerline.

(3) Diameter: was measured at 1.3 m above the ground with diameter tape. The reading was accurate to 0.1 cm. In order to identify dbh, the IUFRO rules were adopted (VAN LAAR and AKCA, 1997). For example, on slopes, the diameter was measured on the uphill side of the tree. dbh was located above the buttresses of the tree to eliminate the variability caused by excessive butt swell, and in the case of irregular stem cross-section caused by protruding branch stumps, the average of two diameters, which were measured above and below, was taken as the true diameter.

(4) Tree height: was measured with the BLUME LEISS height meter and after personal calibration, was estimated in 1 m intervals. In the dense stands, tree heights were estimated by using a 2 m pole or based on the neighbour available measurement of a neighbouring tree.

(5) Social position: According to IUFRO-classification, trees were categorised in different vertical storeys as follows (LEIBUNDGUT 1956):

    a) Upper storey: Tree height > 2/3 of top height
    b) Middle storey: Tree height < 2/3 and > 1/3 of top height
    c) Lower storey: Tree height < 1/3 of top height

(6) Stem quality: was evaluated as good (no external effect), average (one relatively large or several small external defects), or bad (one large or several relatively large external defects).

(7) Developing tendency: was evaluated based on the competition situation of the tree: 1=social ascendancy, 2=social unchanging, 3= social dropping.

(8) Remarks: buttresses, trees status (diseases, dead, crooked, broken off, lianas, infection).

To sampling the natural regeneration, 100 5 x 5 m subplots per site were placed on the left side of the transects in every 10 x 10 m plot as shown in fig 3.3. These subplots covered 25 % of the 1 ha area investigated. All the trees with dbhs < 5 cm were registered and recorded within the following height classes (LAMPRECHT 1989):

- Class A: ≤ 30 cm height. This class included the newly emerging seedlings (denoted as "juveniles")
- Class B: Between 31 cm and 130 cm and dbhs up to 5 cm. This class included established seedlings (denoted as "saplings")

3.2.2 Tree ring sampling

It is known that in the tropics, trees often show no annual ring or show rings, which cannot be used to determine the tree age. However, the existence of a dry season with a length from 2 to 3 months and monthly precipitation less than 60 mm per month is one factor that may induce annual tree rings in the tropics due to seasonal alternating favourable and unfavourable growth conditions (FRITTS 1976, WORBES 1990, 1992, 2001). Periodical flooding of large river systems can also result in a cambial dormancy and formation of annual rings in the wood formation (WORBES 1990). That possibly applies for the research sites, where four months occur with precipitation less than 60mm and aridity indices below 20 (vide 2.2).

For tree ring analysis, five dominant tree species which show distinct annual rings were selected. A total of 70 sample trees (40 from Tuan Dao and 30 from Khe Ro) which had cylindrical, straight boles and no visible damage, were cored at the height of 1.3 m with increment borers and analysed using standard dendrochronology methods in the Georg-August University Göttingen, Germany.

The cores samples were dried and mounted on the wooden support. In order to increase the visibility of the growth zones, the cores were polished with fine sand paper of grit size from 80 to 600 µm. The ring widths were measured to the nearest 0.01 mm using a tree ring measurement device introduced by RINN and TSAP (Time Series Analysis and presentation) programme (RINN 1996). The measured ring-width series of every tree species were cross-dated in order to match variations in the ring width or find the possible false or absent rings (FRITTS 1976). After cross-dating, ring width curves were summarized a mean curves for each species and indexed for further analysis.

3.2.3 Measuring of plant-internal osmotic potential (ψ_π)

3.2.3.1 Plant water relations

Water is considered to be the most important environmental factor influencing plant growth and distribution. The establishment of suitable plant-water relationships is the first requirement for plants to survive (LARCHER 1995). As described by SALISBURY and ROSS (1992), plant growth depends upon water uptake and many plant activities are determined by the properties of water and of substances dissolved in water. Because of its unique chemical properties, water is an excellent overall solvent and is therefore able to dissolve a great amount of chemical substance. Water is also a reactant in many chemical reactions in the plant. Probably the most significant of these is photosynthesis, where water serves as the source of electrons (KRAMER and BOYER 1995).

According to LARCHER (1995), plant water relation is represented as water relations on the plant cell as well as on the whole plant level. Plants can absorb water over their entire surfaces, but the greater part of the water supply come from the soil. KRAMER and BOYER (1995) expressed the soil water potential based on major forces which are involved in the movement of soil water:

$$\psi_w = \psi_m + \psi_s + \psi_g + \psi_p$$

Where, ψ_m is the matrix potential, which describes the surface attraction of soil particles for water. ψ_s represents the osmotic (solute) potential caused by the difference in energy between pure water and water containing dissolved salts. Gravitational potential (ψ_g) describes the force gravity has on water. In dealing with cells, gravitational potentials often can be ignored because they become significant only at heights greater than 1 m in vertical water columns, as in trees. The pressure forces (ψ_p) also can be negligible due to their constant status in the soil compartment.

As described by LARCHER (1995), the water potential of a plant cell consists of osmotic potential and turgor (pressure) potential $\psi_{cell} = -\psi_{\pi} + \psi_{p}$. The osmotic potential (ψ_{π}) is invariably negative, whereas the pressure potential can be positive, zero or in exceptional cases even negative. A negative water potential indicates that the cell as a whole is under tension. In the water-saturated status, ψ_{cell} =0 and $\psi_{\pi} = \psi_{p}$, this results in compensating of wall pressure for the osmotic effect of the cell sap so that net water uptake into the cell is stopped.

MITLÖHNER (2000) concluded from studies of the moist evergreen forest of Diepwalle, South Africa that in evergreen moist forests, where availability of water is always favourable, a particularly high plant water potential (WP) and high plant osmotic potential (OP) within the tree species are great advantage. After MÜLLER-STOLL and LERCH (1993) showed that osmotic values increase depending on wilting time and water deficit as well.

3.2.3.2 Measuring procedure

"Osmotic potential is numerically equal to the osmotic pressure of the soil solution, which is defined as the hydrostatic pressure necessary just to stop the inflow of water when the solution is separated from pure water by a semi-permeable membrane" (cit. WHITE 1987).

Consequently, osmotic potential is considered the important force moving water to and through the cell, and indicates the water balance status of trees (Von WILLERT et al. 1995, SALISBURY and ROSS 1991, LARCHER 1995, KRAMER and BOYER 1995). Trees adapt themselves to the site condition and measuring their internal water status (water potential and osmotic potential) serve a base to evaluate the physiological responses of trees to water stress and their adaptation to the sites (MITLÖHNER 1997a).

Following the measurement procedure introduced by MITLÖHNER (1997a, 1998 and 2002), the measurements of osmotic potential was conducted in the research areas included:

- The $\psi_{\pi, \text{pre-dawn}}$ presents the diurnal relaxation phase of the plant
- The $\psi_{\pi, \text{midday}}$ reflects the actual osmotic situation, i.e. the least favourable environmental condition for the plant. At noon, plants are expected to have relatively high water loss due to high evaporative demand.
- The standardized $\psi_{\pi, \text{sat}}$ are expected to indicate the long-term osmotic constitution of the soil at the given site. This parameter characterizes the soil (influenced by climatic condition) and the adaptation of the plant to it.

For these measurements five dominant and important commercial species were selected for each study site. Six leaf samples per species were taken at midday and predawn. Around midday and before sunrise, the leaf samples were taken. The leaf samples: 1) from the same insertion at 2-5 m; 2) in sunny exposition and 3) only mature leaves were selected. Then the leaves were weighted in the fresh state under field condition using a portable balance with a precision to 0.01 g. After killing-off using a stove in order to avoid enzymatic changes, the samples were packaged in the dry state for transportation.

The standardized osmotic potential values were obtained through artificial water resaturation, whereby twigs of 2 individuals per species per site were cut at pre-dawn, soaked in a water container, and covered by plastic agent in order to prevent evaporation. After one night they were weighed and treated in the same way as leaf samples above.

All samples were transported to Göttingen and analysed in the laboratory of the Institute of Silviculture in the Georg-August University Göttingen, Germany using a cryoscope to determine of the freezing point depression as introduced by KREEB (1990). Firstly, the samples were dried in the oven at 103°C overnight. The oven dried leaves were rebalanced the dry weights in order to determine the actual water content at fresh state in the field and then grounded. 1 g of the powdered sample was mixed with 8 ml of distilled water. In order to dissolve all salts, sugars and organic acids, the suspension was kept in a water bath at 55°C overnight. The leaf material solution was extracted by centrifuging for 15 minutes at 8,000 rotations per minute (Labofuge III, Heraeus GmbH Germany) to separate liquid from coarse contents. Finally, the freezing point depressions of the solutions were measured using a cryscope (Osmometer) (Knauer GMBH, Germany).

Based on the relationship between the freezing point depression of a solution Δ_t (°C) and its osmotic potential ($\pi *_{0°C}$) was recalculated from the measured freezing points using the following equations (KREEB 1990):

$$\pi *_{0°C} = 0.021(\Delta_t)^2 - 12.06\Delta_t$$

$$\pi_{t°C} = \pi *_{0°C} (1 + t°C / 273)$$

where:	Δ_t	is the temperature depression at freezing point
	$\pi *_{0°C}$	is the osmotic potential at 0°C
	$\pi_{t°C}$	is the osmotic potential at t°C

The osmotic potential was recalculated considering the original field water content before dilution. The measurement error from sample collection to cryoscopy is smaller than ± 0.2 MPa (KREEB 1977).

3.2.4 Soil sampling

To characterize soil in the riparian forest areas, from each study area, 10 soil samples were taken from each site at different distances from the river (5, 15, 25, 35 and 45 m) at depths of 10 and 50 cm. The soil samples were analysed at the Soil Laboratory of the Thai Nguyen University and the following chemical parameters were determined using standard procedures (BANG et al. 1975):

- pH_{kcl} using pH meter.

- Organic content (the Tiurin method)
- Total nitrogen (the Kjeldahl method)
- Al^{+++} were measured using a flame atomic absorption spectrophotometer (AAS) ANONYMOUS 2002c).

In order to explain the possible correlation between the concentration of the soil solution and the osmotic potential of trees, soil samples were additionally taken from investigated soil profiles. About 5 g were taken from each soil sample, and the exact fresh weight was determined under field conditions using a portable balance with a precision to 0.01 g. The dry samples were taken to Göttingen to measure the freezing point using the cryoscopic method as described above.

3.2.5 Social methods

In order to get the overview of the areas and be able to describe and understand the utilization and development history of study sites, some RRA (Rapid Rural Appraisal) and PRA (Participatory Appraisal) tools, as described by SCHÖHUTH and KIEVELITZ (1993), were applied as socio-scientific approaches of gathering information. Due to their relevance to the research objectives and characteristics of both sites, the following techniques were used:

a) Secondary data-reviews:

Published and unpublished data related to the research, namely statistics, maps, reports, proposals, case studies and research, were collected in the first field visit to gain an understanding of the general administrative framework and institutions influencing forest management, and to get an overview of the areas. Based on that information, the village Tuan Dao (in Tuan Dao commune) and the village Na O (in Khe Ro Nature Reserve), which have direct influencing to the research sites, were chosen for interviews.

b) Direct and participant observation:

Taking part in daily activities of the villagers with direct observations was expected to result in a better understanding of the areas, the history, influencing factors of study sites, and the respective local societies. In particular, additional background information on the regions was obtained via informal contacts during shared meals, by visiting the forests, by attending the village´s meeting or through chance meetings on the street. The information was documented daily during the research time.

c) Semi-structured interviews:

The semi-structured interview is the most important instrument in RRA as well as in PRA. The topic of interview can be flexibly expanded upon the interviewer, depending on the interview the situation, in order to get more information (FRIEDRICHS 1990, SCHÖNHUTH and KIEVELITZ 1993). In the study areas, the non-standardized interview showed more advantages than a questionnaire because: i) Villagers were afraid that their official answers about forest based activities could lead to penalties in the future. ii) Many villagers were illiterate or could not speak Vietnamese well, especially in Na O, and iii) More information was expected to be obtained by open questions (VU 1999). Instead of a standard questionnaire, a check list of questions were developed. Group discussions and key informant interviews were carried out. In each site, 3 employees of state forest enterprises or forest management board and 10 key informants including older villagers, area well-known persons (men and women) were interviewed. The checklist included the following questions and subjects:

a. Have important natural or social events occurred in the regions?
b. Flooding time of the river? How long? How about in recent years?
c. What is the role of the riparian forest areas? Local knowledge about the role of the forest areas?
d. Why are the forest areas fragmented?

e. Status of the forest area compared with former times? Dominant tree species, diameters, height and volumes? How does it influence the micro condition of the areas (climate, flooding time and effect...)
f. Vegetation composition and tree growth of riparian and non-riparian areas?
g. Harvesting and use activities of the households in the forest areas? Which products (timber, non-timber)? For which aims? How does it contribute to the household income?
h. Management activities (regeneration, thinning, enrichment planting) of households in the contracted areas.
i. Development tendency of the areas? How to conserve and protect these areas?

d) Ranking technique:

After SCHÖNHUTH and KIEVELITZ (1993), this technique can be used for ranking the utilization of resources. In the research sites, the preferred types of timber were ranked by group discussion. The interviewees could choose 10 of 20 most known tree species in the regions and ranked them from 1 (the most important) to 10 (the least important).

3.3 Data analysis

All the data were put into Excel worksheet after the fieldwork as standard format for further analysis. The softwares STATISTICA for WINDOWS, MICROSOFT EXCEL 2000, and the computer program for tree ring analysis TSAP Version 3.0 (RINN 1996) were used in the analysis. Graphics were drawn with STATISTICA 5.1 and MICROSOFT EXCEL 2000.

4. Results and discussion

4.1 Characteristics and forest management history of study sites

An understanding of the regions and both the previous and recent forest management systems are a basic requirement for further development of forest management systems for the regions. For this reason, an overview of the management history of the areas is given here. It focuses on the issue of forest management and utilization over time through social methods described in chapter 3.2.5.

For years, these riparian areas of the investigated rivers were covered with dense primary forest. The forests play an undisputed and vital role in regulating water sources and protecting the watershed area and crops. In addition, forests provide a home and livelihood for a large number of people. Forests contribute a significant amount to the household’s income through fishing, hunting and gathering in the forest, and long rotation agriculture. However, people had unrestricted access to forests and the provision to maintain needed local tree resources received little attention from them.

The Tuan Dao forest was dominated with Fagaceae species, *Vatica tonkinensis* and *Erythrophloeum fordii*, often with stems exceeding dbh > 100 cm dbh. In the period prior to 1996 state forest enterprises had the decisive role in all forest interventions. As the only forest owner they were responsible for management. The forest enterprise established different management units (MU) for each forest sector, whose task focused mainly on organising the extraction activities. These units were responsible for activities such as the exploitation of timber and bamboo following the annual plans of their forest enterprises, the organization of enrichment planting, forest protection, and other management activities inside their areas. The detailed forest management activities were planned and checked every 5 years by forest enterprises. Since recently, only forests which are situated outside the protection zones are still allowed to be harvested. The selective logging system, which has been mostly applied in managing the evergreen natural mixed forests, is implemented as described in table 4.1.

Table 4.1 The selective logging system applied for natural mixed forests with bamboo in Tuan Dao. Required stand volume of 50 m^3/ha and cutting cycle of 35 years (after MARD 2001).

Procedures and activities
1) Logging operation design is fulfilled min. 1 year before harvesting with an allowable deviation of logging volume of ± 10 %: - Determination and mapping of sites, areas and forest blocks. - Determination of logging intensity and rate - Enumeration and marking of harvestable trees
2) Logging indices are identified - Logging intensity included removal and destruction of other trees by harvesting: between 20 and 40 %. For the areas with slope > 15°, logging intensity must decrease 5 % every 10 °. - Exploitable harvestable dbh: 45 cm (for wood groups I and II)*, 35 cm (for wood groups III to VI)* and 25 cm (for wood groups VII and VIII)*.
3) The operations design is checked and approved by the provincial Department of Agriculture and Rural Development.
4) Exploitation permission is issued by province committee
5) Extraction is carried out within 3 months - Felling of the marked trees and transport to the landing within 15 days after felling. - Removal and cleaning of undesirable, dead trees, bamboos, or lianas that hinder growth of commercial trees. In the landing, the cut wood has to be certified with the foresters' hammer.
6) Forest state after extraction is checked and evaluated by the provincial department of Agriculture and Rural Development and local foresters.
7) Forest stands are then closed and maintained until the next felling cycle. All exploitation activities are absolutely forbidden.

* Wood group I-VIII are ranked by wood quality, level of preciousness and use (ANONYMOUS 1995).

During 1982, a large number of *Vatica tonkinensis* trees were harvested by the forest enterprise for railway construction. *Erythrophloeum fordii* were also drastically exploited not only by state forest enterprises, but also illegally by local people selling them on the market or using them for personal construction. On the other hand, the forest was illegally slashed and burnt for cultivating cassava, maize, and other productive agricultural crops. As a result, the actual status of the forest areas is degraded and poor of valuable timber trees. On riparian areas, the forest occurs as fragmented forest stands. The best protected forest stand which still occurs in the area belongs to a village of the Dao ethnic minority. Because of its main function as protection of the water source for the villagers' rice paddy areas, this stand has been protected by the village. Throughout the region, productivity of natural secondary riparian forests has decreased due to commercial timber felling, shifting cultivation, and other uncontrolled exploitation. Extensive deforestation has aggravated flooding and erosion. The riverbed has been enlarged and there has been increased sedimentation. The flooding has become more serious and it lasts much longer than in the times of fully stocked forests. There is a growing recognition that the communities play an important role in forest management practices and the fragmentation of this forest area required an active involvement of local community in forest management. Community-based forest management programs are on the way to be implemented.

Since 1996, the forests have been allocated to the local people for managing. In their forest area, the owner can harvest enough fuel wood to satisfy his/her need. Bamboo shoots and medicinal plants are often extracted and dead *Erythrophloeum fordii* wood is collected for charcoal production. In recent years, bamboos have been continuously exploited in the area under the control of the management unit of Son Dong forest enterprise to sell for a paper production company. When forest cover reaches 80%, the maximum allowable exploitation intensity of bamboo is 90 % of total bamboo stems in a stand (ANONYMOUS 1999). In addition, dead wood of *Erythrophloeum fordii* and other species like *Lithocarpus ducampii* have intensively been gathered to sell.

The Khe Ro forest is one of the richest forests. It has the highest species diversity as well as the highest biomass in the region. In the past, most forest dwelling local communities practiced shifting cultivation. This slash and burn practice was continued by the ethnic groups of Khe Ro and from the neighbouring areas until the government prohibited it at the time of the displacement of the local communities from the restricted forest area due to the establishment of the Nature Reserve. These people are now resettled and cultivate rice paddy and practice agroforestry on their allocated land.

From 1990 to 1995, due to the market´s need, unsuitable decentralized administration in the Nature Reserve, and loosening control on forest management in the area, the forests were extensively exploited not only by local communities but also by the people who came from other provinces throughout the country, like from central Vietnam, i.e. Hue. The villagers said that they had learnt from the outsider how to cut and to sell trees and which tree species were valuable on the market. At that time, most households lived on the timber exploitation and obtained their income from this source. In the forests, the transport paths still exist. *Erythrophloeum fordii*, *Vatica tonkinensis*, *Parashorea chinensis*, and other valuable timber tree species were drastically exploited, especially in the easily accessible areas adjacent to rivers and streams. The many dead stumps of those trees were left over and are evidence of the exploitation. Compared to the period before 1990, the number of species in the Khe Ro forest did not change very much, however, the number of dominant tree species decreased drastically (see table 4.2). In addition, non-timber products were intensively extracted from forest based on local needs and in favour of the local market. The loss of upstream forest cover within the watershed area, combined with the irregular rainfall pattern, leads to more frequent flash flooding and destruction.

Table 4.2 Changes in number and state of trees over time in Khe Ro forest

Species	Prior 1990	2002
Erythrophloeum fordii	Dominant, many big trees	Dominant, few big trees
Vatica tonkinensis	Dominant, many big trees	Domninant, few big trees
Parashorea chinensis	Scattered, big trees	Very few, small trees
Madhuca Pasqieri	Dominant, big trees	Few, small trees
Podocarpus neriifolius	Scattered, big trees	Very few, small trees
Markhamia stipulata	Few big trees	No big trees
Michelia mediocris	Scattered, big trees	Very few, small trees
Rattan and medicinal species	Plentiful	Few
Ficus species	Scattered	Numerous, low
Regeneration	Few light tolerant species	Many light tolerant species

Sources: Khero Forest Management Board and field observation (June 2002).

Since 1995, all decisions regarding forest management goals and operational responsibilities have been more strictly controlled by the Forest Management Board (FMB), which was established by the Bac Giang Provincial People´s Committee (Head of Province) in 1995. The Management Board has 10 staff members, distributed between the headquarters and 3 guard stations. All forest interventions in the strict protection and ecological rehabilitation areas have been forbidden, and are only allowed in the buffer zones by local people. FMB has coordinated with the An Lac Communal People´s Committee (Head of Commune) to establish different forest protection units, which have the mission of preventing all forest utilization activities in the region. These forest protection staff stay in the forests and are responsible for forest protection and tourist organisation. Meanwhile, the forest has been gradually recovering from the long term heavy human impacts. However, because of lack of human resources, equipment, and comprehensive measures in management, illegal utilization of forest products, especially of non-timber products, has not yet been stopped completely.

4.2 Forest products and their uses

In both sites, forest products are used in many ways. The uses can be divided into timber, fuel wood, and non-wood products like Bamboo shoots, fruits, tubers, vegetables, resin, and medical plants. Of 10 interviewed households in Tuan Dao, 90% undertook forest based activities as part time activities to provide supplemental income, whereas in Khe Ro, forest plays an important role in eco-tourism. People from Bac Giang town and neighbouring areas come to Khe Ro for camping, excursions, or simply for relaxing. Money from those activities was partly used to compensate for the costs of the communal forest protection units. Although all forms of forest utilization are forbidden, many villagers, especially poorer villagers, are dependent on additional income from non-timber forest product collection. From the inventory work in the study sites, out of the total 153 plant species recorded in Tuan Dao, 12 % were classified as unclear uses, another 12 % as non-timber forest species, 28 % as fuel wood species and 47 % as timber wood species. In Khe Ro, 43 % of 200 recordable species were timber wood species, 29 % were fuel wood species, 13 % were non-timber forest species, and 16 % were non-use species.

Timber extraction

Wood is used for house construction, furniture, and household utensils. In addition to personal uses, wood is also sold and provides a source of income for the villagers. Although in both areas timber cutting has been forbidden, especially in Khe Ro, illegal exploitation has been continuing. The investigation showed that about 72 frequently used timber tree species occurred at the Tuan Dao site and about 85 in Khe Ro. The most preferred timber tree species in Tuan Dao were *Erythrophloeum fordii, Vatica odorata,* and *Madhuca pasquieri,* while in Khe Ro, besides *Erythrophloeum fordii, Vatica odorata,* and *Madhuca pasquieri,* there were species like *Parashorea chinensis, Forkenia hodginsii,* and *Negeia fleuryi,* which occur in the higher elevation area of the Nature Reserve, and which have continuously been cut illegally due to their high market price. For construction of a house, a substantial quantity of *Erythrophloeum fordii* and *Vatica tonkinensis* timber was needed for house pillars and stairs. These species are preferred because of durability and their long-lasting characteristics. *Forkenia hodginsii* and *Negeia fleuryi* are favourites for interior decoration, wainscot and parquet, because of their light colour and pleasant scent.

Nowadays, because these valuable tree species have been drastically overused, further tree species of the Fagaceae, Lauraceae or Sterculiaceae families have been extracted in Tuan Dao. In Khe Ro, 10-15 new households are built up annually, thus about 40-60 m^3/year for house construction were needed additionally (ANONYMOUS 2002).

The ranking technique was carried out with the interviewees in order to find out the most favoured timber tree species found in the study sites (see chapter 3.2.3). The first ten moat highly ranked species from each site are listed in the table 4.3.

Table 4.3 Most favourite timber tree species in the study sites.

Rank	Tuan Dao	Khe Ro
1	*Erythrophloeum fordii**	*Parashorea chinensis**
2	*Madhuca Pasqieri**	*Erythrophloeum fordii**
3	*Vatica tonkinensis**	*Vatica tonkinensis**
4	*Lithocarpus ducampii*	*Madhuca pasqieri**
5	*Quercus platicalyx*	*Castanopsis indica*
6	*Machilus odoratissima*	*Lithocarpus ducampii*
7	*Ixonanthes cochinchinensis*	*Quercus platicalyx*
8	*Elaeocarpus griffithii*	*Machilus odoratissima*
9	*Caryo daphnopsis*	*Symplocos cochinchinensis*
10	*Symplocos cochinchinensis*	*Liquidambar formosana*

Sources: Group discussion, ranking (April and June, 2002)

*) Rare and precious tree species

Fuelwood extraction

Although in Tuan Dao most households are connected to the central electricity net and in Khe Ro hydro-electric generators are often used to provide light, fuelwood is the main source of energy used for cooking. All small trees, dry bamboos and dead trees are used for this aim. Mainly women, older people, and children are ocupied with gathering fuelwood for the family. From the interview s, it was estimated that a family needs about 15 - 20 kg of fuelwood per day, including wood for cooking pig fodder.

Because forest areas in Tuan Dao belong to production forest categories, people are still allowed to gather dead trees and tree stumps, which were left over in the forest from the last exploitation. Besides providing for household needs, these forest products were sold to dealers from Bac Giang to produce activated charcoal. That provided a considerable amount to household cash, especially in the 2-3 month agricultural slack season between harvests. The most preferred wood for activated charcoal is *Erythrophloeum fordii*, because of its good absorption ability for a wide variety of drugs and chemicals. In this context, it is very effectively used for absorbing poison to treat digestive complaints such as intestinal gas (flatulence), diarrhoea, and stomach ulcer pain (ANONYMOUS, 2004). As a result, this tree species is more and more extracted, including dead trees and stumps. In contrast to the situation of Tuan Dao, in Khe Ro fuel wood is allowed to be taken only from the buffer zone. Because of the remoteness and difficult access of this area, fuel wood is actually limited to personal uses.

Bamboo

Bamboo is extensively used for house construction, fences, and household utensils. In Tuan Dao, bamboo is the main product gathered from the forest and collection has recently been legalized. In Khe Ro, on the other hand, bamboo was illegally collected in the buffer zone, but only for personal use. Bamboos are usually exploited during the dry season, before the new bamboo shoot development. The sale of bamboo from Tuan Dao forest on the market and for the paper company provides cash income for the villagers during the agricultural slack season and contributes to improve the living standard for the households. Because of the richness of the bamboo vegetation within the riparian forest stands, the exploitation activities often take place here (see fig. 4.1). The most common bamboo species are *Lingnania chungii* (McClure), *Noehouzeaua dulloa* (Gamble) A. Camus, and *Ampelocalamus patelleris* (Gamble) Stapleton.

Fig. 4.1 Bamboo exploitation in Tuan Dao (April 2002)

Non-timber forest products (NTFPs)

In both study sites, uses of NTFPs are diverse. They consist of products such as fruits, resins, fodder, bamboo-shoots, tubers, vegetables, and medical plants. Those products are not only gathered for personal use, but also sold to merchants and pharmacy companies to provide income for the family. The extraction intensity differs due to the specific market demands. NTFPs are mainly sold without processing.

In Tuan Dao, NTFP, fuel wood, and bamboo exploitation contribute a significant amount (15 %) to the household income in the village. The extraction of those products is not only done by local people, but also by outsiders who come from neighbouring areas and who want to earn money in their spare time. Among the *Bambusa* species, shoots from *Noehouzeaua dulloa* were said to have been taken out of the forest the most, due to their high demand in the market. Tuan Dao forest also has many fruit bearing trees like *Canarium sp.*, *Nephelium cuspidatum*, *Saurauria dillenioides*, and *Garcinia oblongifolia* which provide edible fruits.

Table 4.4 The commonly used non- timber forest products from Tuan Dao forest.

Species	Vietnamese name	Use	Life form
Ganoderma lucidum	Nam lim	Medicine	Fungi
Garcinia oblongifolia	Bua	Fruit, medicine	Tree
Noehouzeaua dulloa	Nua	Vegebable	Bamboo
Nephelium cuspidatum	Vai thieu rung	Fruit	Average tree
Saurauria dillenioides	Nong la to	Fruit	Bush
Canarium album	Tram trang	Fruit, resin, medicine	Tree
Canarium nigrum	Tram den	Fruit, medicine	Tree
Canarium tonkinensis	Tram chim	Fruit	Small tree
Calamus tetradactylus	May nep	Handicraft, utensils	Rattan
Ampelocalamus patellaris	Giang	Handicraft, utensils	Bamboo
Prunus sp.	Man rung	Medicine	Bush
Dioscorea cirrhosa	Cu nau	Medicine, food	Liana
Schima superba	Voi thuoc	Medicine, drink	Tree
Andropogon muricatus	Huong bai	Medicine	Grass
Licuala fatua	Lui	Decoration, construction	Bush
Tinospora crispa	Day ky ninh	Medicine	Liana
Gnetum montanum	Day gam	Medicine, edible	Liana
Galium aparine	Don xuong	Medicine	Grass

Sources: Group discussion, individual interviews, and field observation (April, 2002)

Table 4.5 The commonly used non- timber forest products from Khe Ro forest.

Species	Vietnamese name	Use	Life form
Canarium album	Tram trang	Fruit, resin, medicine	Tree
Canarium tonkinensis	Tram chim	Fruit	Small tree
Aquilaria crassna	Tram huong	Medicine, resin	Small tree
Garcinia oblongifolia	Bua	Fruit, medicine	Average tree
Noehouzeaua dulloa	Nua	Vegebable	Bamboo
Calamus tetradactylus	May nep	Handicraft, utensils	Rattan
Ampelocalamus patellaris	Giang	Handicraft, utensils	Bamboo
Liquidambar formosana	Sau sau	Resin	Big tree
Dioscorea cirrhosa	Cu nau	Dye, food	Liana
Baccaurea sapida	Dau da dat	Fruit	Small tree
Ficus auriculata	Va	Fruit, food, medicine	Small tree
Schima superba	Voi thuoc	Medicine, drink	Tree
Caryota urens	Moc	Construction, medicine	Small tree
Sauropus grandifolius	Ngot rung	Vegetable, medicine	Small tree
Oroxylum indicum	Nuc nac	Medicine, edible fruit	Tree

Sources: Group discussion, individual interviews, and field observation (June, 2002)

For a long time, medicinal forest products, vegatables, and other edible forest products from this forest area were mainly collected for personal uses only. Interviewees made it known that all medical plants used come from natural forest. This includes remedies for curing their common diseases eg. fever, dermatological, or intestinal diseases. Recently, the effect of an increased demand on the domestic as well as the Chinese market for medical plants and edible forest fruits has lead to increased extraction of those forest products for consumption. For example, Nam Lim *(Ganoderma lucidum.),* a special Linh-zhi fungus strain found on the dead wood and roots of the *Erythrophloeum fordii* tree which is used to cure various digestion and cholesterol problems, can be sold for up to 200,000 VND (15 USD) per kilogram. Due to overexploitation of the *Erythrophloeum fordii* dead wood for producing active coal, the amount of this product has decreased continuously. The multiple uses of non-timber products in Tuan Dao, which were gathered from group discussion, are listed in table 4.4

So far, natural forest plays an essential role in providing food, non-timber forest commodities and medicine in Khe Ro. However, since the transport is very difficult, especially in the rainy season, the extraction of those products in Khe Ro is mainly for personal consumption (see table 4.5). By their own way, local people treat their common diseases with medicinal plants. Despite the fact that it is strictly forbidden, resin of *Canarium album* and also from *Liquisambar formosana* were extracted illegally and sold for producing burning incense, which is always used in ceremonies in Vietnam. Furthermore, *Aquilaria crassna* (Tram huong), a very valuable resin tree for medicine, is winning recognition as commercial prodcut and is gradually becoming a target tree species for illegal extraction. Big trees of this species can no longer be found in the research area.

4.3 Soil characteristics of the study areas

Analysis results of chemical soil properties of the study sites are shown in table 4.6a and b.

Table 4.6a Soil data of Tuan Dao along a transect.

Distance from river bank (m)	Soil depth (cm)	pH_{kcl}	Total C (%)	Total N (%)	Al^{+++} (mol/100g)
5	10	3.15	0.92	0.10	1.98
	50	3.25	0.56	0.08	2.04
15	10	3.16	0.74	0.08	2.04
	50	3.32	1.65	0.21	2.64
25	10	3.07	1.20	0.14	1.98
	50	3.31	0.92	0.11	2.46
35	10	3.51	1.21	0.14	2.28
	50	3.59	0.84	0.10	2.58
45	10	2.81	1.32	0.15	1.86
	50	3.00	0.97	0.10	1.74

Table 4.6b Soil data of Khe Ro along a transect.

Distance from river bank (m)	Soil depth (cm)	pH_{kcl}	Total C (%)	Total N (%)	Al^{+++} (mol/100g)
5	10	3.57	0.75	0.07	0.72
	50	3.63	0.64	0.05	1.26
15	10	3.18	1.22	0.10	0.66
	50	3.03	0.63	0.05	1.02
25	10	3.08	1.23	0.11	1.08
	50	3.12	0.59	0.05	1.14
35	10	3.14	1.12	0.10	1.40
	50	3.06	0.60	0.04	0.84
45	10	3.14	1.12	0.10	1.32
	50	3.12	0.71	0.05	1.14

As can be seen in table 4.6a and 4.6b, the potential fertility of the soil in the study sites is low, which can be demonstrated by thin soil layers (<30 cm) and very low humus content (< 2 %). At a depth of 50 cm, the humus content is even lower than 1 % (0.56 – 0.97 %). The soil is usually wet, resulting in very acidic soil (pH_{kcl} 2.81 – 3.63) and soil in the deeper layer is more acidic than soil at the surface. The N content is very low at both sites (0.05-0.14 %). The degree of mineralisation capacity of organic matter is characterized by the C/N ratios and shows differences between the two sites. Soil samples from Khe Ro have C/N ratios from 11 to 15 due to shortages of nitrogen, as a consequence of the organic matter decomposition process, which is expected to stagnate. In contrast, soil at Tuan Dao has C/N ratios between 7 and 10, indicating stabilized humus. Al^{+++} contents, as a result of the acidic reaction in the soil, are higher at the Tuan Dao site (1.98–2.64 mol/100g), whereas in Khe Ro it is from 0.66 to 1.40 mol/100g. Furthermore, Al^{+++} exchange increase with the soil depth in both sites.

4.4 Floristic analyses

4.4.1 Species-area curves

In a survey of a large area with high diversity, the complete measurement is not feasible or too expensive. Systematic sampling is therefore a reasonable solution, which provides reliable data with a reasonable effort (KRAMER and AKCA 1995). However, the minimum representative area has to be reached in the inventory. Concerning tree species composition, the minimum representative study area is best determined based on the species-area curve (LAMPRECHT 1989). According to this idea, the survey should be continued until no more new species appear in the sample transect. Species-area curves were drawn by counting tree species recorded in sample units in an accumulative manner.

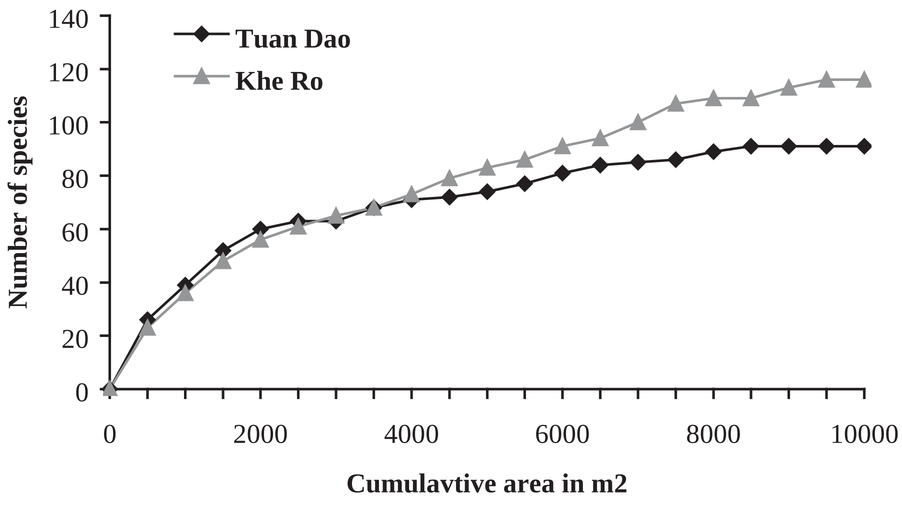

Fig. 4.2 Species-area curves of all trees of dbh ≥ 5 cm in two secondary riparian forest areas, Tuan Dao and Khe Ro, NE Vietnam.

As shown in figure 4.2, the species number found in Khe Ro forest is 118, higher than that in Tuan Dao forest (92 species). In Tuan Dao the species-area curve rise sharply in the first 3000 m^2, then flattens and is relatively plateaued between 6000 to 8000m^2. For this forest area, an accumulated area of 8000 m^2 is regarded as the minimum representative area. In Khe Ro, however, the upper part of the curve shows a gradual increase up to an area of 9000 m^2. It can be assumed that the minimum required study areas for these two forests are reached by less than 1 hectare and sampling size has been representative in terms of species diversity.

4.4.2 Important tree species and families in the study areas

In order to find out the importance of the tree species, Importance Value Index developed by CURTIS & McINTOSH (1951), is often used. The Importance Value Index (IVI) is calculated for each tree species and family according to the expression:

$$IVI = \text{relative abundance} + \text{relative dominance} + \text{relative frequency} \qquad (4.1)$$

where abundance is the number of individuals per ha
dominance is the basal area per ha
frequency is the percentage of subplots in which a given species occurred

In the present study, all the tree species with dbh ≥ 5 cm (minimum surveyed dbh) in Tuan Dao and Khe Ro sites were computed and ranked by IVI. The 15 most important species and families are presented in tab. 4.7 and 4.8.

Table 4.7 Abundance, dominance, frequency and Importance Value Index (IVI) of tree species in Tuan Dao and Khe Ro, NE Vietnam. All trees ≥5 cm dbh.

Rank	Species	Abundance (N/ha)	Dominance (m^2/ha)	Frequency (%)	IVI
a) Tuan Dao					
1	*Mischocarpus oppositifolius*	54	1.6	70	20.2
2	*Gironniera subaequalis*	54	1.2	80	18.1
3	*Pygeum arboreum*	46	1.0	65	15.4
4	*Vatica tonkinensis*	23	1.6	35	14.4
5	*Erythrophloeum fordii*	26	0.7	45	10.1
6	*Cylindrokelupha chevalierii*	30	0.5	55	9.7
7	*Canarium album*	27	0.4	65	9.3
8	*Eurya nitida*	25	0.2	75	8.4
9	*Garcinia oblongifolia*	26	0.4	55	8.4
10	*Macaranga denticulata*	32	0.2	45	7.8
11	*Schima superba*	20	0.4	50	7.6
12	*Xylopia vielana*	21	0.4	55	7.6
13	*Wrightia tomentosa*	21	0.5	35	7.5
14	*Lithocarpus ducampii*	10	0.7	40	7.4
15	*Canarium tonkinensis*	18	0.3	60	6.9
16-92	Other species	355	5.9		141
1-92	Total	788	16.1		300
b) Khe Ro					
1	*Vatica tonkinensis*	105	4.6	10	31.7
2	*Engelhardta chrysolepis*	88	1.4	5	15.6
3	*Pithecellobium clypearia*	70	1.1	30	13.8
4	*Catanopsis indica*	55	1.3	10	11.9
5	*Lithocarpus ducampii*	17	0.7	60	8.0
6	*Maesa balansae*	50	0.5	5	7.5
7	*Eurya persiaefolia*	45	0.2	15	6.4
8	*Erythrophloeum fordii*	22	0.8	10	6.2
9	*Aporusa dioica*	28	0.4	20	5.9
10	*Pygeum arboreum*	17	0.3	45	5.6
11	*Mischocarpus oppositifolius*	13	0.6	25	5.4
12	*Quercus platicalyx*	4	0.6	45	5.3
13	*Daphniphyllum atrobadium*	25	0.2	35	5.3
14	*Elaeocarpus griffithii*	15	0.8	5	5.3
15	*Madhuca pasquieri*	9	0.7	15	4.8
21-118	Other species	420	8.5		162
1-118	Total	983	22.6		300

From table 4.7, it can be seen that tree species with dbh $\geq$ 5 cm in both study areas are relative dense. The abundance varies from 788 stems per ha in Tuan Dao to 983 stems per ha in Khe Ro. There is no clearly dominating tree species in Tuan Dao, the first ranked tree species, *Mischocarpus oppositifolius* has an IVI value of 20.2, whereas the second, *Gironniera subaequalis,* constitutes 18.1. In Khe Ro *Vatica tonkinensis* is listed as the most important species, with an IVI of 31.7, and an abundance of 105 stems (10.7%). In addition, with high abundance, low frequency, and high dominance, *Vatica tonkinensis* in Khe Ro has characteristics of a certain tendency to form clusters (LAMPRECHT 1972). There is evidence is that this species occurs in widely separated, small and large groups in the area. In both areas, the economically important tree species such as *Vatica tonkinensis* and *Erythrophloeum fordii* still commonly occur, although they were strongly exploited in the past. This can be explained by the fact that only the big logs of these species are really valuable. Another reason is that *Vatica tonkinensis* in Khe Ro are often located on cliffs or other difficult to access areas. Nevertheless, more than half of tree species fell into the auxiliary species group, which are described as species with low abundance, low frequency and low dominance (LAMPRECHT 1972). These species often have neither ecological nor economical importance. Silvicultural treatments such as improvement thinning and elimination of lianas and undesirable trees would be needed to improve this situation.

Table 4.8 Abundance, dominance, frequency and Importance Value Index (IVI) of tree family in Tuan Dao and Khe Ro, NE Vietnam. All trees ≥ 5 cm dbh.

Rank	Family	Abundance (N/ha)	Dominance (m^2/ha)	Frequency (%)	IVI
a) Tuan Dao					
1	Sapindaceae	57	1.7	90	22.7
2	Euphorbiaceae	81	0.7	85	19.8
3	Ulmaceae	54	1.2	90	19.3
4	Fagaceae	33	1.5	70	17.5
5	Burseraceae	49	0.9	100	17.3
6	Rosaceae	46	1.0	85	17.0
7	Theaceae	52	0.7	95	16.4
8	Mimosaceae	48	0.7	90	15.7
9	Dipterocarpaceae	23	1.6	35	15.0
10	Lauraceae	39	0.7	90	14.4
11	Apocynaceae	30	0.6	70	11.4
12	Caesalpiniaceae	26	0.7	60	11.2
13	Clusiaceae	27	0.4	55	9.0
14	Annonaceae	21	0.4	65	8.6
15	Myristicaceae	24	0.3	65	8.4
16-44	Other families	178	3.1		76
1-44	Total	788	16.1		300
b) Khe Ro					
1	Dipterocarpaceae	107	4.7	45	34.6
2	Fagaceae	82	2.9	80	26.9
3	Mimosaceae	132	1.7	70	26.0
4	Juglandaceae	91	1.5	60	20.1
5	Euphorbiaceae	53	1.6	85	18.3
6	Theaceae	94	0.6	75	17.5
7	Lauraceae	64	0.8	90	16.4
8	Caesalpiniaceae	30	1.0	50	10.9
9	Rubiaceae	31	0.5	55	9.1
10	Elaeocarpaceae	17	0.9	40	8.3
11	Myristicaceae	20	0.3	55	7.4
12	Myrtaceae	13	0.5	55	7.3
13	Moraceae	20	0.3	50	6.6
14	Sapindaceae	15	0.6	30	6.4
15	Burseraceae	21	0.2	45	6.3
16-49	Other families	193	4.5		78
1-49	Total	983	22.6		300

The highest IVI per families were for Sapindaceae, Euphorbiacea, Ulmaceae, Fagaceae, and Burseraceae in Tuan Dao, whereas the Khe Ro forest is dominated by Dipterocarpaceae, Mimosaceae, Juglandaceae, Fagaceae, and Euphorbiaceae (see tab. 4.8). The IVI of the families does not vary much among the first 10 families. It varies from 14.4 % (Lauraceae) to 22.7 % (Sapindaceae) in Tuan Dao and from 8.3 % (Elaeocarpaceae) to 34.6 % (Dipterocarpaceae) in Khe Ro. The trend that few families exhibit a great proportion of IVI, density and basal area has been recorded in several studies of Brazilian forests (MARIMON et al. 1997). Some of these important families were also found in freshwater swamp forests of the Southern Malay Peninsulas (YAMADA 1997).

4.4.3 Species diversity

Species diversity is a key indicator of biodiversity conservation and regarded as the number of distinct species in a forest community or stand (GREIG-SMITH 1983). In the silvicultural sense, the term species diversity is used to include species number, diversity indices and frequencies of a given species, which are considered important indications of stand diversity. The flood interruption and its duration can impact on species richness and diversity (DEILLER et al. 2001), which raises the question of whether the extant high diversity riparian vegetation will remain in these periodical flooding areas of the present study.

In a sample of one hectare, a large number of tree species (trees with dbh $\geq$ 5 cm) were found in the study. In Tuan Dao 788 trees were included in the investigation. These belonged to 92 species, whereas in Khe Ro the number of tree species was 118, out of a total 983 trees. Many of these species were present in very low abundances (see tab. 4.7). This actual result is comparable to the well-known characteristic of tropical rain forests to have a high proportion of tree species with few stems (GENTRY 1988). A similar trend was also found in the tropical riparian fragments in Belize, Central America (PILTHER and KELLMAN 2002). Further high diversity results have been documented in other riparian forest areas. In the upper Rhine alluvial hardwood forest, DEILLER et al. (2001) found that although more woody species are found in the flood non-affected sites, the periodically flooded site showed the highest diversity of tree species in the extant vegetation. PAULA et al. (1996) counted in the gallery forest at the Córrego dos Macacos of Brazil up to 1,741 trees with dbh >5 cm belonging to 116 tree species. In the last existing fragment of closed gallery forest in the Delta du Saloum National Park, Senegal, 24 species and 369 individuals ≥ 5 cm dbh in 0.6 ha were found (LYKKE and GOUDIABY 1999).

Frequency diagram

The frequencies are expressed as the occurrence or absence of a given species in a subplot (LAMPRECHT 1989). They give an approximate indication of the homogeneity of a stand. According to their absolute frequencies the investigated species are assigned to five different classes (see table 4.9).

Table 4.9 Tree frequency classes used in frequency diagram according to LAMPRECHT (1989).

Classes	Frequency class
I	1 – 20 %
II	21 – 40 %
III	41 – 60 %
IV	61 – 80 %
V	81 – 100 %

The frequencies depend on the sample size and the size of the subplots. In the study areas, a complete sample size of one hectare and 20 subplots of 500 m^2 was selected. The frequency of tree species and families from two study areas are illustrated in the figure 4.3.

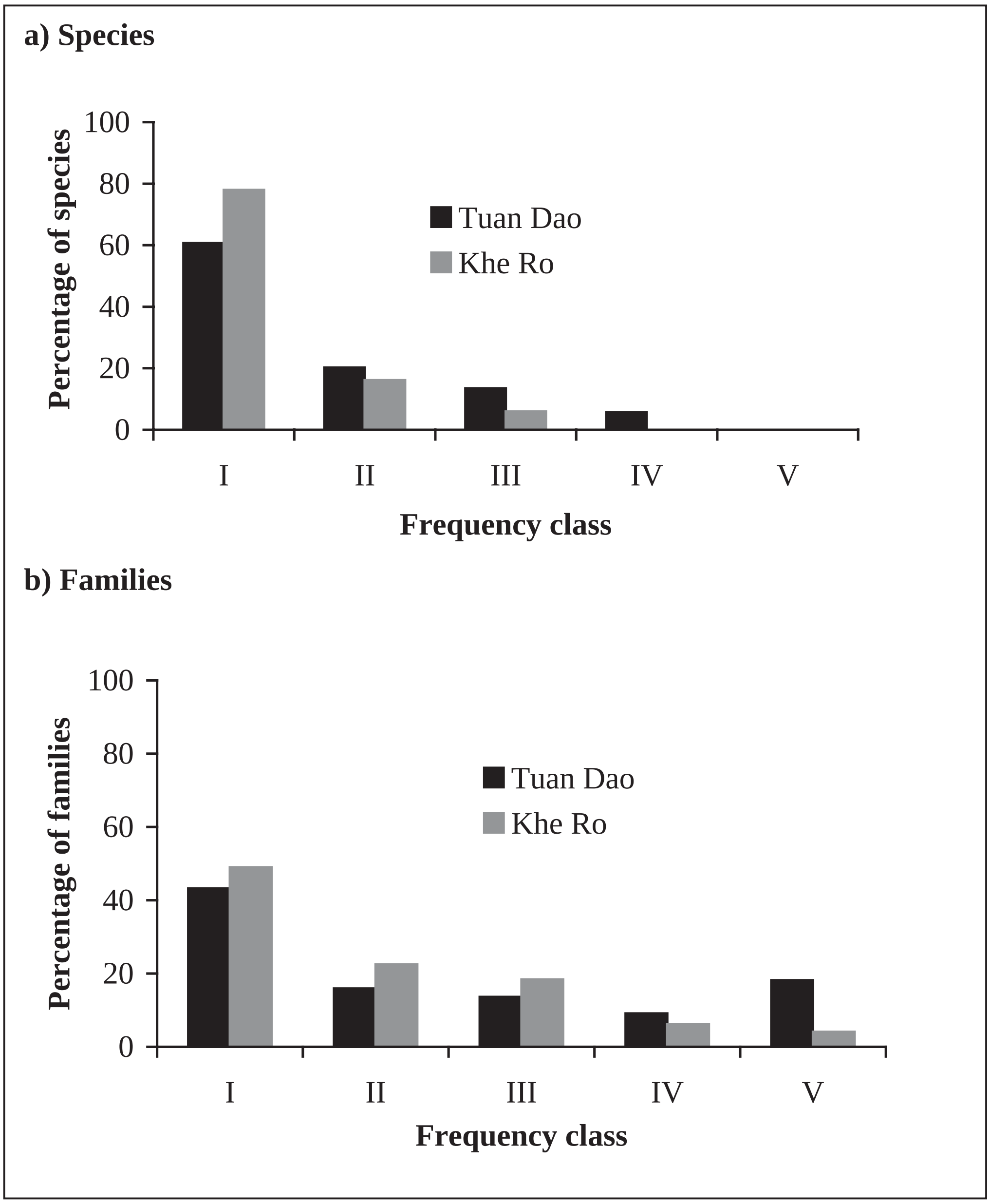

Fig. 4.3a, b Frequency diagrams and number of tree species and families per frequency class (dbh ≥ 5 cm) in two investigated riparian forest areas, Tuan Dao and Khe Ro, NE Vietnam.

As can be seen from fig. 4.3a, almost all investigated tree species in Tuan Dao were presented in four frequency classes from I to III and only 5 species are found in class IV. According to LAMPRECHT (1989), high value in classes I and II and low value in IV and V indicates a high degree of floristic heterogeneity. A frequency diagram of Khe Ro shows a higher degree of heterogeneity, whereby tree species are frequent only in three classes and most of species belong to classes I and II. There are no species in the higher classes IV and V.

In contrast to the situation found by species, the tree families were distributed in all frequency classes (see fig. 4.3b). Whereas in Khe Ro there were more tree families in classes I, II, III, in Tuan Dao trees from classes I to IV were more common (except for class V, where the number of tree families in Tuan Dao is 8, higher than those in Khe Ro).

Diversity indices

Another important way to quantify species diversity is by using diversity indices. A diversity index is a mathematical measure of species diversity in a given stand (RICHARDS 1996). From the silvicultural point of view, different levels of disturbance have different effects on species diversity. If the goal is to preserve biodiversity in a given area, it is necessary to be able to understand how diversity is impacted by different management strategies. Because diversity indices provide more information than simply the number of species present (i.e., they account for some species being rare and others being common), they serve as valuable tools that enable foresters to quantify diversity in a community and describe its numerical structure.

Simpson's diversity index (D) is one of the most meaningful and robust diversity measures available. The index is calculated as the proportion of species i relative to the total number of species (p_i) (SIMPSON 1949). The form of the index appropriate for a finite community is:

$$D = \frac{\sum_{i=1}^{k} n_i \cdot (n_i - 1)}{N \cdot (N - 1)} \qquad (4.2)$$

where n_i number of individuals in the species i

k number of species

N total individuals (species)

D takes a value between 0 and 1, with 1 being complete evenness. When D increases, diversity decreases and SIMPSON´s index is expressed as 1-D (MAGURRAN 1988).

The SHANNON diversity index (*H´*) is one of the most enduring of all diversity measures (MAGURRAN 1988). Shannon's index accounts for both abundance and evenness of the species represented and is based on the rationale that the diversity, or information, in a natural system can be measured in a similar way to the information contained in a code or a message. It is calculated from the equation:

$$H' = -\sum_{i=1}^{k} p_i \cdot \log p_i \quad \text{where} \quad p_i = \frac{n_i}{N} \qquad (4.3)$$

where p_i proportional abundance of species *i*
k number of species

As a heterogeneity measure, the SHANNON index takes the degree of evenness in species and abundances into account. Evenness (*E*) is calculated as a proportion of observed and maximal diversity (PIELOU 1969).

$$E\% = \frac{H'}{H_{\max}} \cdot 100 \qquad (4.4)$$

where E % evenness
H´ SHANNON index
H_{max} maximum possible diversity

There are two different interpretations of evenness (E). FRÄNZLE (1977) indicates the low E as expression for high diversity of species composition. MAGURRAN (1988), however, interprets high diversity as an even distribution of species.

In the present work, the SHANNON-WIENER-Index, the SIMPSON index, as well as evenness are used for evaluating diversity levels of researched forest stands. The calculated indices are recorded in table 4.10.

Table 4.10 Tree species diversity of two study areas. Trees with dbh ≥ 5 cm.

Site	Abundance (N/ha)	Basal area (m^2/ha)	SIMPSON index (1-D)	SHANNON index (H´)	Evenness (E)
Tuan Dao	788	16.1	0.97	3.89	86
Khe Ro	983	22.6	0.96	3.87	81

The table 4.10 show that the investigated forest stands have high diversity grades. SIMPSON indices range from 0.96 to 0.97 and SHANNON-WIENER indices vary from 3.70 to 3.89. Prior studies on riparian forest next to streams gave that the permanence of flooding and site condition effects around river may be impacted in developing adjacent forest composition and the diversity generally increases with the reduction of flood permanence and deep (GOSSELINK and TURNER 1978). For the riparian forest in East Kalimantan, Indonesien, RICHTER (1998) had found a significant difference of evenness between the inundation forest (E = 25 %) and the riparian forest (E = 73 %). The SHANNON-WIENER and SIMPSON indices were between 2.5 and 3.7 respective 1.2 to 1.4. The evenness varies from 58 % to 84 % (VARGHESE and KUMAR 1997). In this case of study, the short flood permanency in the directly adjacent zones of research areas might be considered as a reason for that situation.

However, evenness calculated from the site of the newly reserved habitat, Khe Ro (E = 81%) is a bit lower than in the site from the regularly disturbed habitat, Tuan Dao (E = 86 %). Here, the light condition of forest may play a crucial role for growing of more light-tolerant species in Tuan Dao. That confirms the state of GENTRY (1982) that in the tropics, diversity of the climax forests is considerably high.

4.4.4 Species similarity

For floristic comparison among sites, SÖRENSEN (1948) proposed to use the so-called "coefficient of similarity". The SÖRENSEN´s coefficient of similarity is calculated according with numbers of species and use of the formula:

$$K_s = \frac{2 \cdot c}{a + b} \cdot 100 \qquad (4.5)$$

where a is the number of species in survey A

b is the number of species in survey B

c is the number of species common to both surveys

K_s presents floristically comparison between stands and gives value from 0, which indicates completely difference, to 100, which presents floristically identical stands. The fact that common and rare species get the same weighting by using this index, which can reduce their importance in the vegetation analysis. LAMPRECHT (1969) has modified this method by using dominances instead of species numbers. The corrected formula is as follow:

$$K_d = \frac{\sum d_c}{\sum d_a + \sum d_b} \cdot 100 \qquad (4.6)$$

where $\sum d_a$ is the total dominance survey A

$\sum d_b$ is the total dominance survey B

$\sum d_c$ is the total of the dominances of both surveys of common species

The resulting values show a high similarity between two sites. The modified index (K_d) after LAMPRECHT, which based on dominance of species, gives higher similarity value by 71.6 %. The basal areas of common species in Tuan Dao occupied 74.6 % and

69.5 % in Khe Ro. However, in term of floristic composition, only 49 common species were found in both stands from 92 species in Tuan Dao and 118 species in Khe Ro. K_s is by 46.7 %, which indicates a lower similarity as compared to K_d.

4.4.5 Species distribution in different gradients

River effect on the changes in species distribution in different distance may be important in determining adjacent forest composition. It contributes effective tools for future silvicultural approaches.

Because there was lack of basic researches on site condition of study areas and difficult situation of present research, 2 different gradients were identified based on interviewed results and field observation. It was shown that in both areas, flooding come and leave fast and impact to the distance of 25 m from the riverbank, therefore two separated zones were noted. Accordingly, the gradient analysis were implied for 2 different zones: Zone I (1-25 m from the river): where was influenced strongly and more regularly from the flooding. Zone II (25 to 50 m from river bank) where was not influenced from flooding in the rainy season.

The results of floristic composition along gradient away from the rivers are recorded in table 4.11a and b.

Table 4.11a Abundance, dominance, frequency and Importance value index (IVI) of tree species ≥ 5 cm dbh of varying distances from the river at Tuan Dao, NE Vietnam

Rank	Species	Abundance (N/ha)	Dominance (m^2/ha)	Frequence (%)	IVI
Zone I: 1-25 m from the river					
1	*Vatica tonkinensis*	32	3.0	25	23.4
2	*Gironniera subaequalis*	56	1.4	80	21.1
3	*Mischocarpus oppositifolius*	52	1.4	55	19.8
4	*Pygeum arboreum*	38	0.8	60	13.0
5	*Erythrophloeum fordii*	28	1.0	40	12.3
6	*Canarium album*	26	0.6	50	11.0
7	*Aporosa dioica*	34	0.6	35	10.0
8	*Eurya nitida*	30	0.2	30	9.9
9	*Wrightia tomentosa*	32	0.6	30	9.4
10	*Garcinia oblongifolia*	28	0.4	35	8.9
11	*Xylopia vielana*	24	0.4	30	8.9
12	*Canarium tonkinensis*	22	0.2	40	8.7
13	*Lithocarpus ducampii*	10	1.0	30	8.4
14	*Cylindrokelupha chevalierii*	26	0.4	35	8.3
15	*Macaranga denticulata*	30	0.2	40	7.4
16-71	Other species	350	2.6		120
1-71	Total	818	17.2		300
Zone II : 25-50 m from the river					
1	*Mischocarpus oppositifolius*	56	1.8	55	23.2
2	*Pygeum arboreum*	54	1.2	70	20.6
3	*Gironniera subaequalis*	52	1.0	60	17.6
4	*Cylindrokelupha chevalierii*	34	0.6	50	12.0
5	*Schima superba*	24	0.6	60	11.3
6	*Erythrophloeum fordii*	24	0.6	35	9.5
7	*Garcinia oblongifolia*	24	0.4	45	9.4
8	*Canarium album*	28	0.2	45	8.8
9	*Macaranga denticulata*	34	0.2	30	8.4
10	*Litsea baviensis*	16	0.4	40	8.1
11	*Eurya nitida*	20	0.2	40	7.1
12	*Xylopia vielana*	18	0.2	35	6.6
13	*Elaeocarpus griffithii*	10	0.6	15	6.1
14	*Lithocarpus ducampii*	10	0.4	20	5.6
15	*Memecylon scutelletum*	14	0.2	30	5.6
21-76	Other species	340	6.6		140
1-76	Total	758	15.2		300

Table 4.11b Abundance, dominance, frequency, and Importance value index (IVI) of tree species ≥ 5 cm dbh at varying distances from the river at Khe Ro, NE Vietnam.

Rank	Species	Abundance (N/ha)	Dominance (m^2/ha)	Frequency (%)	IVI
Zone I: 1-25 m from the river					
1	*Vatica tonkinensis*	104	5.2	50	34.7
2	*Catanopsis indica*	68	1.6	60	18.4
3	*Pithecellobium clypearia*	66	1.4	60	16.9
4	*Engelhardta chrysolepis*	72	1.2	25	13.7
5	*Eurya persiaefolia*	58	0.2	30	9.3
6	*Maesa balansae*	48	0.4	25	8.5
7	*Lithocarpus ducampii*	20	1.2	25	8.4
8	*Erythrophloeum fordii*	26	1.0	25	8.4
9	*Daphniphyllum atrobadium*	42	0.2	30	7.8
10	*Elaeocarpus griffithii*	18	1.0	25	7.6
11	*Bischofia trifoliata*	2	1.4	5	6.3
12	*Madhuca pasquieri*	10	0.8	15	5.6
13	*Quercus platicalyx*	8	1.2	5	5.5
14	*Aporosa dioica*	14	0.4	30	5.5
15	*Garcinia oblongifolia*	16	0.4	50	5.3
16-100	Other species	436	8.2		138
1-100	Total	1,008	25.4		300
Zone II: 25-50 m from the river					
1	*Vatica tonkinensis*	106	4.2	25	34.4
2	*Engelhardta chrysolepis*	104	1.8	35	23.1
3	*Pithecellobium clypearia*	74	1.0	40	16.4
4	*Catanopsis indica*	42	1.0	40	12.9
5	*Maesa balansae*	52	0.6	20	10.1
6	*Machilus odoratissima*	30	0.4	45	9.2
7	*Aporosa dioica*	32	0.4	35	8.4
8	*Mischocarpus oppositifolius*	16	0.8	15	7.4
9	*Pygeum arboreum*	20	0.4	35	7.4
10	*Gironniera subaequalis*	16	0.6	30	7.3
11	*Elaeocarpus griffithii*	12	0.6	25	6.8
12	*Eurya persiaefolia*	32	0.2	25	6.6
13	*Erythrophloeum fordii*	18	0.6	15	6.4
14	*Ternstroemia gymnanthera*	22	0.2	30	6.4
15	*Carallia diplopelata*	16	0.2	25	5.3
16-85	Other species	366	9.4		132
1-85	Total	958	19.9		300

From table 4.11a it can be seen that the results from Tuan Dao indicate that zonation has a slight impact on tree species association. There was a significant decrease in the number of *Vatica tonkinensis* in the less frequently flooded area(zone II). This species has an IVI of 23.4 % and is ranked as the most important species in zone I, but in zone II the IVI value is only 4.7 %. Total stem number in zone I is also higher than that of zone II.

Conversely, the research results from Khe Ro show that the forest composition did not vary remarkably with distance from the river, demonstrating that there is no big change in species composition in different riparian zones (I and II) (see table 4.11b). In both zones *Vatica tonkinensis* dominate, making up 34.7 % in zone I and 34.4 % in zone II. As a consequence of the small channel characteristic of the stream and the flood interruption, floods in this area may not yet be considered a potential source of changes in vegetation composition.

Several studies have indicated that riparian forests are a reflection of interacting processes operating at different scales (cf. MacDONALD et al. 2004). Confirming prior studies on riparian forest next to streams, this research showed that topographic effects around a river may be important in determining adjacent forest composition. The results of the present study suggested that *Vatica tonkinensis* in Khe Ro were dominant in the vast majority of stands on sites with a slope $\geq$ 10 %. On flat topographic positions, however, there was a higher frequency of soft wood species and inundation tolerant species like *Pithecellobium clypearia*.

In order to see whether the frequency and diversity differ across gradient zones away from the riverbank, the percentage of species from different frequency classes and diversity indices were calculated separately for different gradients (table 4.12)

Table 4.12 Tree diversity and frequency classes in different gradient zones of two natural secondary riparian forests, Son Dong, NE Vietnam. Zone I is 1 to 25 m from the riverbank; Zone II is 25 to 50 m from the riverbank.

Site	Species number (n)	SIMPSON index (1 - D)	SHANNON index (H´)	Percentage of species in frequency classes			
				I	II	III	IV
Tuan Dao	92						
Zone I	66	0.97	3.75	71.2	22.7	4.5	1.5
Zone II	76	0.97	3.87	65.8	22.4	7.9	3.9
Khe Ro	118						
Zone I	92	0.97	3.87	81.5	15.2	3.3	-
Zone II	91	0.96	3.70	85.7	11.0	3.3	-

As can be seen from table 4.12, there is no clear difference in diversity levels between zones, Diversity indices between zones I and II show no big differences.

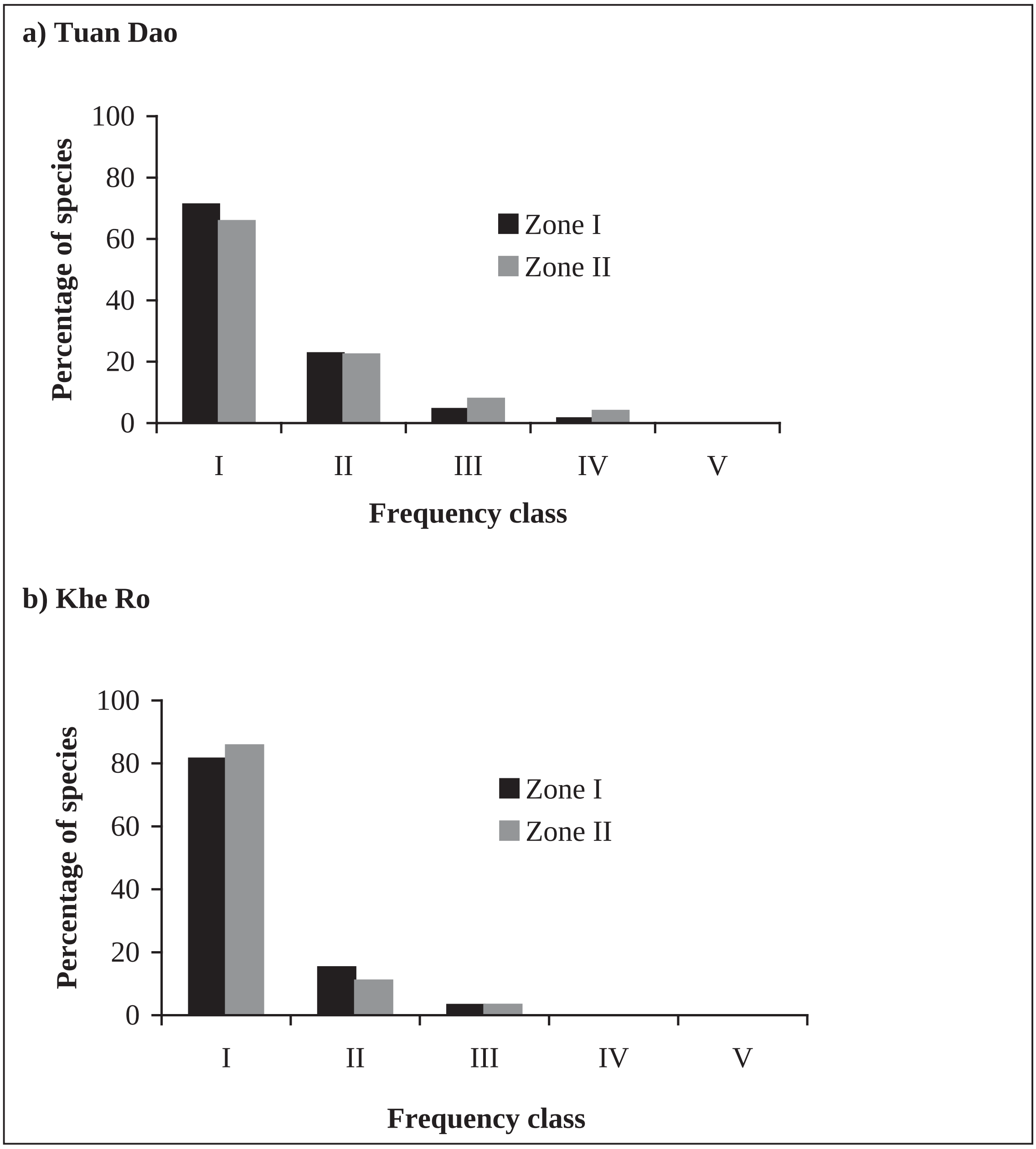

Fig. 4.4 Frequency classes and percentage of tree species per frequency classes in different distances from river in Tuan Dao (a) and in Khe Ro (b).

As shown in table 4.12 and figure 4.4, despite the finding that in Tuan Dao the tree number per frequency classes in zone II seems to be larger than in zone I, the analysis of variance (ANOVA, $p<0.05$) amongst riparian zones in both areas shows no significant difference in frequency and species number between zones I and II. The lack of difference in frequency of species between zones shows that period flooding has no clear influence on the tree frequency in these areas.

4.4.6 Vegetation characteristics of the current riparian forest areas

MacDONALD (2004) found that an important characteristic of the riparian forest buffer strips along rivers is that the tree communities are younger on average than those of the surrounding landscape, because trees near rivers have been cut more frequently. In the present study, both areas are dominated by the aggressive, fast-growing light-demanding species like *Macaranga denticulate, Wrightia tomentosa*, and *Eurya nitida* in Tuan Dao and *Engelhardta chrysolepis, Maesa balansae*, and *Aporusa dioica* in Khe Ro. The forest compositions of these study areas are comparable to GRÄFE´s description of phase of pioneer forest development (GRÄFE 1981). According to GRÄFE, these forest stands might belong to the second phase of pioneer forest development. Nevertheless, based on the actual species composition today, the forests can be classified as previous climax successional stratum of *Erythrophloeum fordii* forests (TRAN 1970). The presence of an indicator tree species in the Khe Ro,riparian area, *Pithecellobium clypearia*, which was ranked as the third most common tree species (with IVI of 13.8 %), may be considered as an evidence of the possible influence of flooding on vegetation communities here (FSIV 1998).

In the investigated areas, stands had higher species richness and density compared to the results of TRAN (1994), carried out in the upland zonal forests of Son Dong. In the present study, a high abundance of species such as *Vatica tonkinensis*, *Mischocarpus oppositifolius*, *Pithecellobium clypearia*, *Eurya sp.*, *Catanopsis sp.*, *Carallia diplopelata*, *Bischofia trifoliata* and other flood tolerant species like *Ficus* was found.

Possibly due to river-bank effects, forest trees in zone I have lateral crown growth in the direction of light and grow toward the water. This is especially true of trees occurring directly adjacent to the water. The structure of the vegetation is affected by the tilting or bending of trees. Similar circumstances and tendencies were also found by HALLÉ et al. (1978).

The pattern of vegetation most often observed in riparian forests is that species composition changes along a gradient of flooding frequency. Frequent references have reduced species numbers in the understorey of the forests, particularly in the wettest portions of the floodplain (LUGO et al. 1990). An example from the riparian forest of Mexico shows that associations of *Pachira* and *Ficus* or shrub species like *Mimosa pigra* and *Bravaisia tubiflora* are common along river or lagoon fringes. In Vietnam, the investigations in some wetland areas showed that there are often no occurrences of aquatic vegetation in the lower stratum of fresh water wetlands like Nui Coc, Song Da Reservoirs. Actually, the natural vegetation in those riparian areas include young secondary forests and bamboo dominated stands with dense shrubs and grasses, especially *Imperata cylindrica, Rhodomyrtus tomentosa, Melastoma candidum,* and *Cratoxylum sp*. (SCOTT 1989, VANKERKHOVE et al. 1993).

KREEB (1983) stated that the thick and impenetrable under-growth and jungle vegetation are often found in the riparian forest strips as well as in the successional stratum of secondary forests after clearing. In the Tuan Dao study site, the high abundance of bamboos, *Macaranga denticulate*, lianas, and grasses which often occur along the rivers and streams in Bac Giang, characterised the areas with special influence of period flooding (TRAN 1994 and ANONYMOUS 1999). The study result shows that bamboos constitute 25 % of the total number of trees < 5 cm dbh in compartment B. *Macaranga denticulate* occupies almost 3 % and lianas and grasses more than 2% of this forest area. Likewise, in Khe Ro bamboos make up more than 20 % of total investigated understorey plants (trees < 5 cm dbh). In Khe Ro neither *Macaranga denticulate*, grass species, nor lianas (about 1 %) were abundant (see table 4.13).

Table 4.13 Absolute and relative abundance of typical understorey life-forms and species from two secondary riparian forests, Tuan Dao and Khe Ro, NE Vietnam. All tree species < 5 cm dbh.

Lifeform	Abundance			
	Tuan Dao		Khe Ro	
	absolute (n/ha)	relative (%)	absolute (n/ha)	relative (%)
Macaranga denticulata	536	4.8	-	-
bamboos	2780	25.0	2680	20.3
lianas	268	2.4	148	1.1
grasses	232	2.1	-	-
shrubs	320	2.9	1132	8.6
Total	4136	37.2	3960	30.0

The species compositions of bamboos in the two areas differ from each other. While in Tuan Dao *Lingnania chungii* McClure (Poaceae) and *Noehouzeaua dulloa* Gamble A. Camus (Poaceae) are the main species, in Khe Ro *Noehouzeaua dulloa* Gamble A. Camus (Poaceae) and *Bambusa sp*. are more dominating.

The development of this vegetation in an almost explosive manner over the entire forest floor (30-37 % of total species < 5 cm dbh) can prevent the successful regeneration of both gap opportunists and shade-tolerant trees. The lower percentage of these forms of ground vegetation is found in the more closed stand (Khe Ro). Regarding the influence of rivers on the occurence of this vegetation, the percentages of this type of vegetation are calculated at different distances from the rivers (1-5m, 10-15 m, 20-25 m, 30-35 m, and 40-45 m), the results are represented in figure 4.5

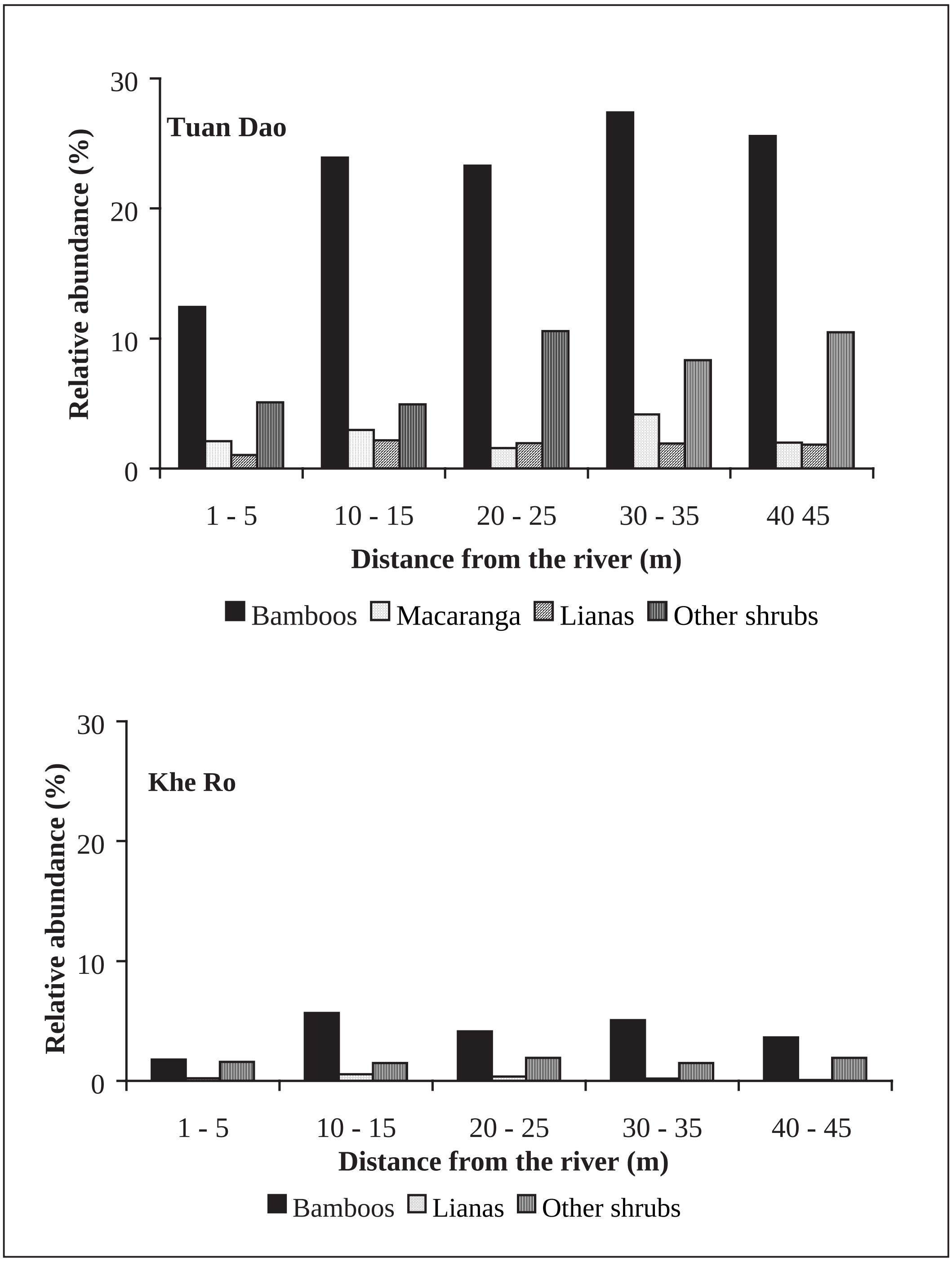

Fig. 4.5 Relative abundance of typical life-forms and species and their variation at different distances from the riverbank of two natural secondary riparian forests, Tuan Dao and Khe Ro. All tree species <5 cm dbh.

Figure 4.5 shows a high variation of the relative abundance of these species at different distances from the rivers (also see 3.2.1). Tuan Dao clearly has a higher percentage of the understorey life forms and species than Khe Ro. In both areas, in the strip directly on the edge of the river (1-5 m from the rivers), a lower percentage of vegetation was found as than at other distances from the river. An explanation for poorer understorey development here may be due to the unfavourable growth condition resulting from regularly flooding. Bamboos are the most common type of vegetation in all gradients and increase slightly in frequency with the distance from the river edge. In the former shifting cultivation or logging areas, the over-cut patches are rapidly overgrown with bamboos and other shrub and herb vegetation. That overwhelming dominance can hinder the spontaneous development of secondary forests here.

4.5 Horizontal structure

4.5.1 Standard error

Variability of an estimate depends on the sampling method, sample size, and the variability among the unit value in the population. A sample estimate is almost worthless without some indication of its accuracy. Therefore, standard error is used as a parameter of the confidence limits of a sample mean by judging the quality of an estimator statistician (KRAMER and AKÇA 1995). A small standard error indicates that the possible sample means are concentrated in a close neighbourhood of the estimator’s mean value. A larger standard error, in contrast, allows for larger deviation from the latter. Ideally, an effective estimator should be unbiased and have a small standard error. The standard error ($S_{\bar{x}}$) is obtained from the variance and sample size of a population and computed with the following equation:

$$S_{\bar{x}} = \frac{S_x}{\sqrt{n}} \qquad \text{i.e.} \qquad S_x = \frac{\sum_{i=1}^{n} x_i - \bar{x}}{\sqrt{n-1}} \qquad (4.6)$$

where
- $S_{\bar{x}}$ is standard error
- S_x is the variance computed from a sample
- n is sample size
- x_i is the value of the i^{th} unit in the sample
- $\bar{x}$ is the arithmetic mean value of the sample

Table 4.14 The mean basal area ($\bar{x} \pm S_x$), standard deviation (S_x), and standard error in percent ($S_{\bar{x}}$ %) in the study sites. All trees ≥ 5 cm dbh.

Site	Sample size (n)	Sample area (m^2)	$\bar{x} \pm S_x$ (m^2)	$S_{\bar{x}}$ %
Tuan Dao	20	10,000	0.80 ±0.18	5.2
Khe Ro	20	10,000	1.13±0.38	7.3

The standard errors of both sites are found to be < 10% (see table 4.14). This means that the present inventory design represents the "reality" with a very low error.

4.5.2 Mean diameter and basal area

The average diameter and basal area of stand are very useful parameters for quantifying a forest stand and relate directly to silvicultural and management decision (van LAAR and AKCA 1997).

The **average diameter at breast height (dbh)** is occasionally used to describe a relatively homogeneous stand. The arithmetic- or quadratic- mean dbh is calculated for the study areas with following functions:

Arithmetic mean diameter

$$\bar{d} = \frac{\sum_{i=1}^{n} d_i}{n} \qquad (4.7)$$

where d_i diameter of i^{th} tree

n sample size

Quadratic mean diameter

$$d_q = \sqrt{\frac{\sum_{i=1}^{n} d_i^2}{n}} \qquad (4.8)$$

These mean values are generally used in conjunction with estimates of the number of trees per ha to determine competition within a stand. In addition, they can be compared with the median and mode dbh to determine if the diameter distribution is skewed. The quadratic mean diameter has a stronger correlation to stand volume than the arithmetic mean (BRACK 1999). In the heterogeneous stands of this study it is more effective to use d_q.

Stand basal area (*G*) (m^2/ha) is simply defined as the cross-sectional area of all the trees at breast height per hectare of a forest stand. It is generally expressed as square units per unit area (Van LAAR and AKCA 1997). Tree basal area is used to determine percent stocking. It is related to tree volume, biomass, and crown parameters. For the stand, basal area is related to stand volume and biomass as well as correlated with competition or the density of a stand. LAMPRECHT (1972) regarded the basal area of tree species as better than their abundance as a measure for of their ecological importance. The following equation is used to calculate the basal area from measurements of the diameter (dbh in cm) of trees in a given stand (BRACK 1999):

$$G(m^2) = \sum g_i \quad \text{where} \quad g_i(m^2) = \frac{\pi}{40000} \cdot d_i^{\,2} \qquad (4.9)$$

where G is stand basal area

g_i is basal area of i^th^ tree

d_i is dbh of i^th^ tree

Results from calculating the different mean diameters of the two study stands and at different distances away from the rivers are summarised in table 4.15

Table 4.15 Arithmetic mean diameter ($\bar{d} \pm S_d$), standard deviation (S_d), quadratic mean diameter (d_q), and basal area (G) for both study areas and at different distances away from the rivers, NE Vietnam. All trees ≥ 5 cm dbh. Zone I: 1-25 m from the river; Zone II: 25-50 m from the river.

Site	$\bar{d} \pm S_d$ (cm)	d_q (cm)	G (m^2/ha)
Tuan Dao	14.2 ± 7.7	16.1	16.1 ± 0.18
Zone I	14.2 ± 8.0	16.3	17.1 ± 0.06
Zone II	14.1 ± 7.4	15.9	15.0 ± 0.04
Khe Ro	14.1 ± 9.7	17.1	22.6 ± 0.36
Zone I	14.4 ± 10.7	17.9	25.4 ± 0.11
Zone II	13.9 ± 8.4	16.2	19.7 ± 0.91

According to table 4.15, the standard deviations of the research parameters are very high in all cases; they ranges from 52.5 to 74.3 %. Khe Ro shows stronger variation in dbh, with a coefficient of variation of 68 %. The coefficients of variation in dbh for zone I (56.3 % for Tuan Dao and 74.3 % for Khe Ro) are also higher than those of zone II (52.5 % for Tuan Dao and 60.4 % for Khe Ro). This may be caused by the wide spectrum of diameters of both areas, from 5 cm to 52 cm in Tuan Dao and from 5 cm to 96 cm in Khe Ro.

The arithmetic means of the diameters show no difference between the two sites, where $\bar{d}$ of Tuan Dao is 14.2 cm and that of Khe Ro is 14.1 cm. The quadratic mean diameter (d_q) of Khe Ro is, however, slightly higher than that of Tuan Dao. Moreover, trees of zone I have comparatively higher quadratic mean diameters than those of zone II at both sites. Total basal area varies from 15.0 m^2/ha in zone II of Tuan Dao to 25.4 m^2/ha in zone I of Khe Ro (see tab. 4.15). Correspondingly, the total basal area of Khe Ro is higher than that of Tuan Dao (see tab. 4.15). The zone Is have higher basal area than zone IIs. In brief, the areas closer to the watercourses (zone I) harbour higher quadratic mean diameters and basal areas compared to those of zone II.

The former intensive utilization history of the stands and the location adjacent to river might explain why the stand basal areas per ha found in this study are considerably lower compared with results from many studies carried out in zonal natural forests (ANONYMOUS 2002). This is also lower than the research results which have been documented in other riparian forests. RICHTER (1998) calculated a density of 17.9 m^2/ha with trees $\geq$ 10 cm dbh for natural secondary riparian forest in East Kalimantan. NATTA (2000) assumed 41.5 m^2/ha for all riparian forest sites of Benin. Woody plants in the last existing fragment of closed gallery forest in the Delta du Saloum National Park of Senegal had a stand basal area of only 12.6 m^2 for trees $\geq$ 5 cm dbh (LYKKE and GOUDIABY 1999).

4.5.3 Diameter distributions

The relationship between tree number and diameter distribution is important for inferring past disturbances, regeneration patterns, and successional trends in tree population (LAMPRECHT 1989, APEL 1996). Several functions have been successfully used for modelling diameter distributions like the normal distribution, Weibull´s distribution, Beta distribution, Gamma distribution ,or decreasing distribution (VAN LAAR and AKCA 1997).

Consisting of trees of many ages and a large number of small trees with decreasing frequency as the diameter increases, the study stands are said to be uneven-aged (HUSCH 1963). For those uneven-aged selection forests which result from irregular selective logging, the decreasing distribution, which is also called an inverse J-shaped distribution, have been proven to be best used for demonstrating n/D (MEYER 1952, LAMPRECHT 1989, NGO 1998, Van LAAR and AKCA 1997). The inverse J-shaped diameter distribution can be expressed by the negative exponential equation:

$$n = k \cdot e^{-a \cdot d} \tag{4.10}$$

where n is number of stems per ha
k, a are constants
d is diameter of the trees

Another logarithmic J-shape function $n = e^{(k \cdot e^{-a \cdot d})}$ (4.11), proposed by LU (1999), is said to be better used in higher diameter classes.

For the study stands, the diameter distributions were fitted using the functions 4.10 and 4.11. Observed and predicted stem number of trees with dbh $\geq$ 5 cm were computed with the STATISTICA programme and are presented in table 4.16. It can be seen in this table that the values predicted with the logarithmic J-shape are higher than the observed values in both stands. In contrast, the values predicted with a negative exponential function in Khe Ro are lower than the observed values.

The constants of functions and R^2 values of diameter distribution were estimated at the same time and compiled in table 4.16. Based on the coefficient of determination (R^2), both functions, negative exponential and logarithmic J-shape, show a good fit with diameter size distribution. R^2 values are very high, ranging from 0.96 to 0.99. In Tuan Dao, a negative exponential curve was found to fit the diameter distribution better than the logarithmic J-shape.

Table 4.16 Comparison of fitted diameter distributions with two inverse J-shape functions (4.10 and 4.11) of Tuan Dao and Khe Ro, NE Vietnam. All tree ≥ 5 cm dbh.

dbh class (cm)	Tuan Dao			Khe Ro		
	Obs. (n)	$n_1(d)$	$n_2(d)$	Obs. (n)	$n_1(d)$	$n_2(d)$
5-9.9	290	307.9	310.2	437	433.6	439.5
10-14.9	224	194.0	186.2	232	237.8	225.7
15-19.9	138	122.3	116.9	124	130.4	124.7
20-24.9	71	77.0	76.6	75	71.5	73,5
25-29.9	28	48.5	52.1	49	39.2	45.9
30-34.9	13	30.6	36.6	22	21.5	30.2
35-39.9	15	19.3	26.6	19	11.8	20.8
40-44.9	3	12.1	19.9	13	6.5	14.9
45-49.9	5	7.7	15.2	2	3.6	11.1
50-54.9	1	4.8	11.9	3	1.9	8.5
55-59.9	-	-	-	1	1.1	6.7
60-64.9	-	-	-	3	0.6	5.5
65-69.9	-	-	-	1	0.3	4.5
75-79.9	-	-	-	1	0.2	3.9
>80	-	-	-	1	0.1	3.3
Total	788	824.2	852.1	983	960.1	1018.8

__Note:__ obs. = observed values

$n_1(d) = k \cdot e^{-a \cdot d}$ (negative exponential function)

$n_2(d) = e^{(k.e^{-a \cdot d})}$ (logarithmic J-shape function)

Table 4.17 J-shape functions and coefficient of determination (R^2) of stem diameter distributions in Tuan Dao and Khe Ro, NE Viet Nam.

Site	Negative exponential function ($n_1(d)$)		Logarithmic J-shape function ($n_2(d)$)	
	$n_1(d)$	R^2	$n_2(d)$	R^2
Tuan Dao	$n = 488.6 \cdot e^{(-0.0924 \cdot d)}$	0.98	$n = e^{6.297 \cdot e^{(-0.0186\, d)}}$	0.96
Khe Ro	$n = 790.8 \cdot e^{(-0.1202 \cdot d)}$	0.99	$n = e^{6.834 \cdot e^{(-0.02319 \cdot d)}}$	0.99

Additionally, the size-class distribution of trees with dbh ≥ 5 cm is drawn. Here, higher abundance is found in the smaller size classes. The typical right-skewed diameter distributions present a more pronounced decreasing pattern in Khe Ro than that in Tuan Dao. The observed decreasing curve is typical in natural forest regenerating from seed and this shape is characteristic of climax stadium and selective stands after selective logging (WHITMORE 1990, LAMPRECHT 1989, NGO 1998). This distribution type also describes a stand with many small individuals and few large ones. The maximum observed dbh in Tuan Dao is only 52.1 cm, whereas in Khe Ro it is 96.3 cm.

Similar results in diameter class distribution were found in the riparian forests of Belize, where about 78 % of trees fell in the smallest dbh class (10-20 cm). 50 % of trees in a riparian forest of East Kalimantan belong to the diameter class 10-20 cm (RICHTER 1998). In a riparian forest in Benin, 76.4 % of stems were in the diameter class < 30 cm (NATTA 2000). A similar diameter distribution was also presented in several studies implemented in zonal secondary natural forests of the tropics (LU 1999, NGUYEN 2000, KYAW 2003, GEBREHIWOT 2003, BRODBECK 2004).

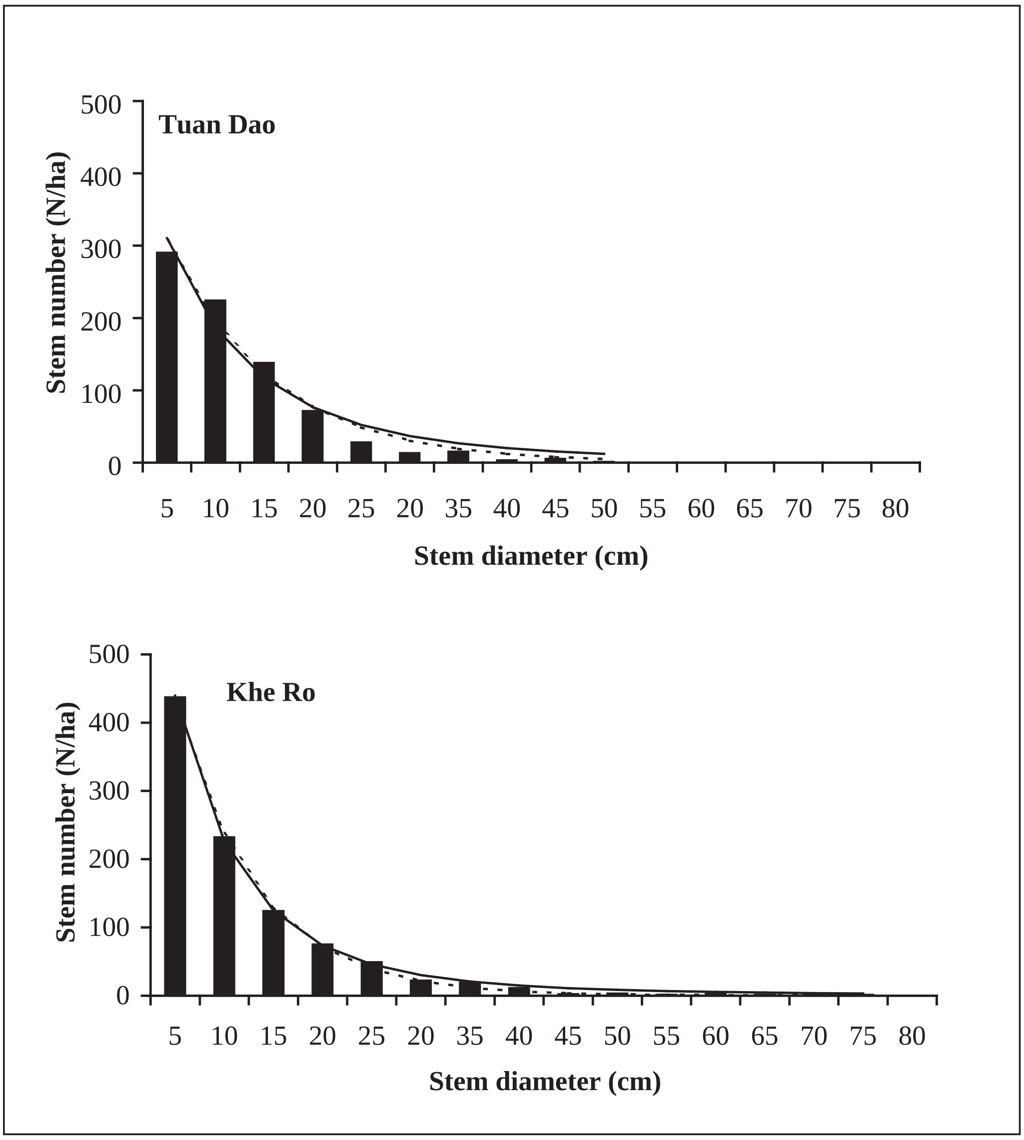

Fig. 4.6 Diameter distributions in two secondary riparian forests of Tuan Dao and Khe Ro, NE Vietnam. All trees ≥ 5 cm dbh.

Observed values (bar charts), fitted curve with negative exponential function (dotted line) and fitted curve with logarithmic J-shape function (full line).

$n_1(d) = k \cdot e^{-a \cdot d}$ (negative exponential function)

$n_2(d) = e^{(k.e^{-a \cdot d})}$ (logarithmic J-shape function)

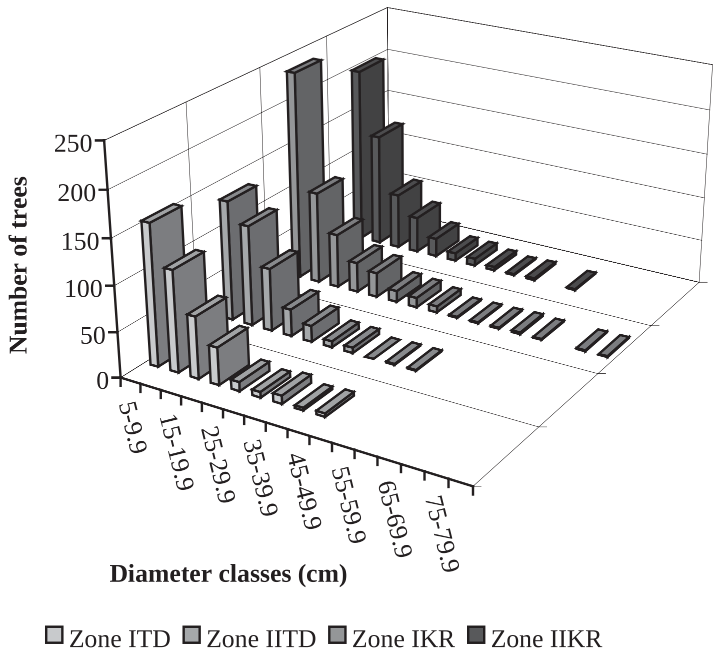

Fig. 4.7 Diameter distribution in different riparian zones in two secondary natural riparian forests in Son Dong, NE Vietnam.

Zone ITD	is diameter distribution of zone I in Tuan Dao
Zone IITD	is diameter distribution of zone II in Tuan Dao
Zone IKR	is diameter distribution of zone I in Khe Ro
Zone IIKR	is diameter distribution of zone II in Khe Ro

Along all riparian zones of the study areas, diameters are distributed in the form of a decreasing distribution (see fig. 4.7). In both zones (I and II) of the study areas, about 80 % of trees fall in small diameter classes under 20 cm. Nevertheless, zone I consists of more trees with greater dbh.

4.6 Vertical structure

4.6.1 Diameter-height relations

In the stand, the relationship between height and diameter is of stochastic nature. By plotting measured height over diameters, the heights are estimated from an adequate sample of heights. This h/d relationship of a stand can be demonstrated in the form of a graph, which is called a stand height curve. These height curves represent the existing state of the stands with regard to the relationship of diameter to height at the time of the inventory (PRODAN 1965, LOETSCH et al. 1973, KRAMER and AKÇA 1995). In the plenty-storey forests, the stand height curve is similar to growth curve. LOETSCH et al. (1973) concluded that in tropical inventories, the merchantable tree height is only weakly correlated with the reference diameter. In order to fit height curves, a variety of functions have been proposed and tested in numerous tropical research projects (SCHMIDT 1967, Van LAAR and AKCA 1997, NGUYEN 2000, KYAW 2003, BRODBECK 2004). The following equations were applied to test the appropriate height curve in this study:

Table 4.18 Equations used to fit height curves in the natural secondary riparian forests of Tuan Dao and Khe Ro, NE Viet Nam.
h is tree height, **d** is diameter at breast height, $\mathbf{b_0, b_1, b_2, b_3}$ are constants.

Equation	Number	Author/Description
$h = b_0 + b_1 \cdot d + b_2 \cdot d^2$	1.	Parabola (PRODAN 1965)
$h = 1.3 + \frac{d^2}{b_0 + b_1 \cdot d + b_2 \cdot d^2}$	2.	PRODAN´s equation (1944)
$h = 1.3 + \left(\frac{d}{b_0 + b_1 \cdot d}\right)^2$	3.	PETTERSON´s equation (1955)
$h = e^{b_0 + b_1 \cdot \ln d + b_2 \cdot (\ln d)^2}$	4.	KORSUN´s equation (1948)
$h = b_0 + b_1 \cdot \ln d$	5.	Logarithmic equation (PRODAN 1965)
$h = e^{b_0 + b_1 \cdot \ln d + b_2 \cdot d}$	6.	FREESE´s equation (1964)
$h = e^{b_0 + b_1 \cdot \ln d}$	7.	Van LAAR and AKCA (1997)
$h = 1.3 + b_1 \cdot d + b_2 \cdot d^2$	8.	Van LAAR and AKCA (1997)
$h = 1.37 + b_1 \cdot (1 - e^{-b_2 \cdot d})$	9.	Van LAAR and AKCA (1997)
$h = b_1 \cdot (1 - e^{-b_2 \cdot d})$	10.	Van LAAR and AKCA (1997)
$h = b_1 \cdot \left(\frac{d^{b_2}}{b_3 + d^{b_2}}\right)^{b_3}$	11.	Van LAAR and AKCA (1997)
$h = e^{b_0 + b_1 \cdot \frac{1}{d}}$	12.	Van LAAR and AKCA (1997)

For the study sites, the relationship of height to diameter at breast height was tested with all 12 functions by all trees with dbh $\geq$ 5 cm at the Tuan Dao and Khe Ro study sites. Results affirmed the correlation of height to diameter in both sites. The parabola proposed by PRODAN (1965), proved to be the best fitting function with the highest coefficient of correlation: 0.71 in Tuan Dao and 0.63 in Khe Ro (see fig. 4.8).

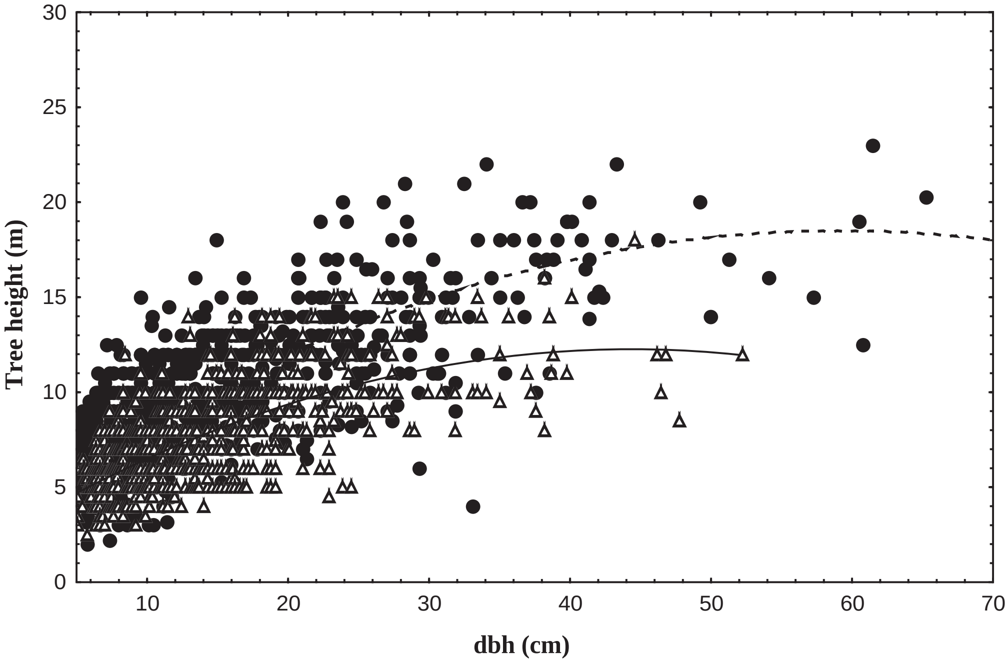

Fig. 4.8 Stand height curves of two natural secondary riparian forests, Tuan Dao and Khe Ro, NE Vietnam. All trees ≥ 5 cm dbh. Fitted with Parabola equation (1) (PRODAN 1965).

$h_{Tuan\ Dao} = 2.627629 + 0.4348028 \cdot d - 0.0049084 \cdot d^2$, r = 0.71.
Observed heights = empty triangles (Δ); fitted heights = full curve
$h_{Khe\ Ro} = 3.605959 + 0.5038704 \cdot d - 0.00426 \cdot d^2$, r = 0.63
Observed heights =filled dots (●). Fitted heights = dotted curve

Following LOETSCH et al. (1973), the precision of the height curves depends on the scatter of the point cloud around the curve and on the number of measured heights. In the study areas, a standard error ($S_{\bar{h}}\%$) of $\pm 0.88\,\%$ is expected for height curve of the Tuan Dao site and of $\pm 0.75\,\%$ for height curve of Khe Ro site. Moreover, the standard deviations of both height curves exceed $\pm 20\,\%$: 24.7 % for height curve of Tuan Dao and 23.6 % for height curves of Khe Ro. The point cloud that was obtained in figure 4.7 shows higher scattering in Tuan Dao, which indicates the lower homogeneity of this stand compared with those in Khe Ro (LOETSCH et al. 1973). Furthermore, the height curves are relatively flat, and flatter in Tuan Dao, which is in agreement with LOETSCH et al. (1973), who described that the slope of the height curve is steeper on the good site and much more flat on the poorer sites.

After Van LAAR and AKCA (1997) the shapes of height curves vary among sites and are related to site conditions. Furthermore, the slope of the height curve is to a large extent a characteristic of tree species (LOETSCH et al. 1973). Thus, separate height curves were developed for the important tree species, namely *Mischocarpus oppositifolius*, *Erythrophloeum fordii*, *Vatica tonkinensis*, *Pygeum arboreum*, and *Canarium album* in Tuan Dao and *Vatica tonkinensis*, *Erythrophloeum fordii*, *P. clyperaria*, *Castanopsis indica*, *P. arboreum* and *Canarium album* in Khe Ro.

Table 4.19 Non-linear estimation to fit height curves of important tree species in Tuan Dao and Khe Ro, NE Vietnam.

Species	Non-linear fitted function	N	R
Tuan Dao			
Mischocarpus oppositifolius	$h = e^{0.2204296 + 1.983212 \cdot \ln d - 0.394684 \cdot (\ln d)^2}$	54	0.78
Pygeum arboreum	$h = 2.803224 + 0.4510967 \cdot d - 0.0046727 \cdot d^2$	46	0.69
Vatica tonkinensis	$h = 3.794423 + 0.4451194 \cdot d - 0.0064581 \cdot d^2$	26	0.75
Erythrophloeum fordii	$h = 1.3 + 0.7943293 \cdot d - 0.0141215 \cdot d^2$	23	0.77
Lithocarpus ducampii	$h = 4.7983374 + 0.1849815.d + 0.0012966.d^2$	10	0.87
Canarium album	$h = e^{0.9595228 + 1.0487414 \cdot \ln d + 0.0042994 \cdot d}$	27	0.89
Khe Ro			
Vatica tonkinensis	$h = 3.017947 + 0.5843132 \cdot d - 0.0051101 \cdot d^2$	105	0.85
Pithecellobium clypearia	$h = -1.3064015 + 10.401807 \cdot \ln d$	70	0.71
Erythrophloeum fordii	$h = 6.3972174 + 0.269801 \cdot d + 0.0007341 \cdot d^2$	22	0.85
Castanopsis indica	$h = e^{0.2966555 + 2.142208 \cdot \ln d - 0.0287704 \cdot d}$	5	0.75
Pygeum arboreum	$h = e^{1.4426415 + 0.2437206 \cdot \ln d + 0.0399511 \cdot d}$	7	0.86
Canarium album	$h = e^{1.357225 + 0.5820935 \cdot \ln d + 0.0258055 \cdot d}$	15	0.83

As presented in table 4.18, equations No. 1, 4, 5, 6, and 8 were found to be the best fitted functions for the diameter-height relationship of these tree species.

GEBREHIWOT (2003) stated that R^2 values for the diameter-height relationship of *Boswellia papyrifera* Del. (Burseraceae, and *Acacia etbaica* P. Mill. (Fagaceae) in Northern Ethiopia increased from open to closed sites. BRODBECK (2004) also found that R-values for tree height curves of natural forests are higher than those of forest gardens in Central Sulawesi. In this study, the diameter-height relationships of tree species *Erythrophloeum fordii*, *Vatica tonkinensis*, and *Pygeum arboreum* in Khe Ro are stronger than those in Tuan Dao. In contrast, the diameters of the light tolerant tree species, *Canarium album* of Tuan Dao, which has lower wood density and occurs where there are more light gaps, correlated better with the height parameters. The growth relationship of tree species in the study sites are clarified in fig. 4.8 and 4.9

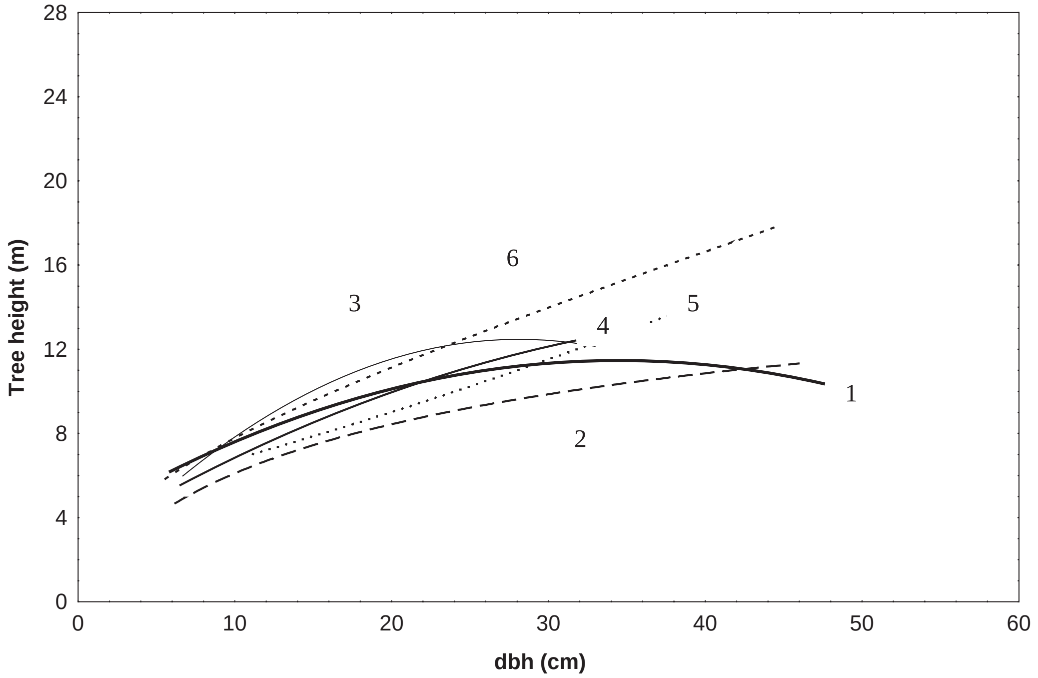

Fig. 4.9 Fitted height curves for tree species of Tuan Dao, NE Vietnam.

(1): *Vatica tonkinensis*; Fitted with equation 1., r =0.75.

$$h = 3.794423 + 0.4451194 \cdot d - 0.0064581 \cdot d^2$$

(2): *Mischocarpus oppositifoliu s*; Fitted with equation 4., r=0.78.

$$h = e^{0.2204296 + 1.983212 \cdot \ln d + 0.394684 \cdot (\ln d)^2}$$

(3): *Erythrophloeum fordii*; Fitted with equation 8., r=0.77.

$$h = 1.3 + 0.7943293 \cdot d - 0.0141215 \cdot d^2$$

(4): *Lithocarpus ducampii*; Fitted with equation 1., r=0.87.

$$h = 4.7983374 + 0.1849815.d + 0.0012966.d^2$$

(5): *Pygeum arboreum*; Fitted with equation 1., r=0.69.

$$h = 2.803224 + 0.4510967 \cdot d - 0.0046727 \cdot d^2$$

(6): *Canarium album*; Fitted with equation 6., r=0.89

$$h = e^{0.9595228 + 1.0487414 \cdot \ln d + 0.0042994 \cdot d}$$

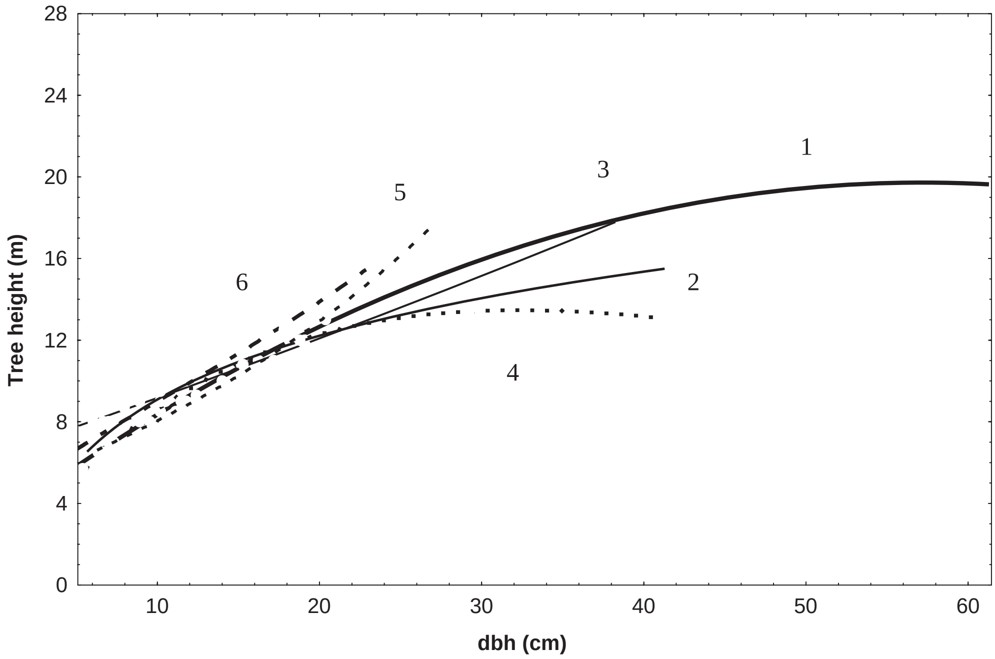

Fig. 4.10 Fitted height curves for tree species in Khe Ro, NE Vietnam.

(1): *Vatica tonkinensis*; Fitted with equation 1., r =0.85.

$$h = 3.017947 + 0.5843132 \cdot d - 0.0051101 \cdot d^2$$

(2): *Erythrophloeum fordii*; Fitted with equation 1., r=0.85.

$$h = 6.3972174 + 0.269801 \cdot d + 0.0007341 \cdot d^2$$

(3): *Pithecellobium clypearia*; Fitted with equation 5., r=0.71.

$$h = -1.3064015 + 10.401807 \cdot \ln d$$

(4): *Castanopsis indica*; Fitted with equation 6., r=0.75.

$$h = e^{0.2966555 + 2.142208 \cdot \ln d - 0.0287704 \cdot d}$$

(5): *Pygeum arboreum*; Fitted with equation 6., r=0.86.

$$h = e^{1.4426415 + 0.2437206 \cdot \ln d + 0.0399511 \cdot d}$$

(6): *Canarium album*; Fitted with equation 6., r=0.83

$$h = e^{1.357225 + 0.5820935 \cdot \ln d + 0.0258055 \cdot d}$$

In the figures 4.9 and 4.10, all tree species show relatively steep height curves. The height curves of fast grow tree species *Pithecellobium clyperaria*, *Pygeum arboreum* and *Canarium album* are clearly steeper than those of *Vatica tonkinensis*, *Erythrophloeum fordii*, *Castanopsis indica* and *Lithocarpus ducampii*.

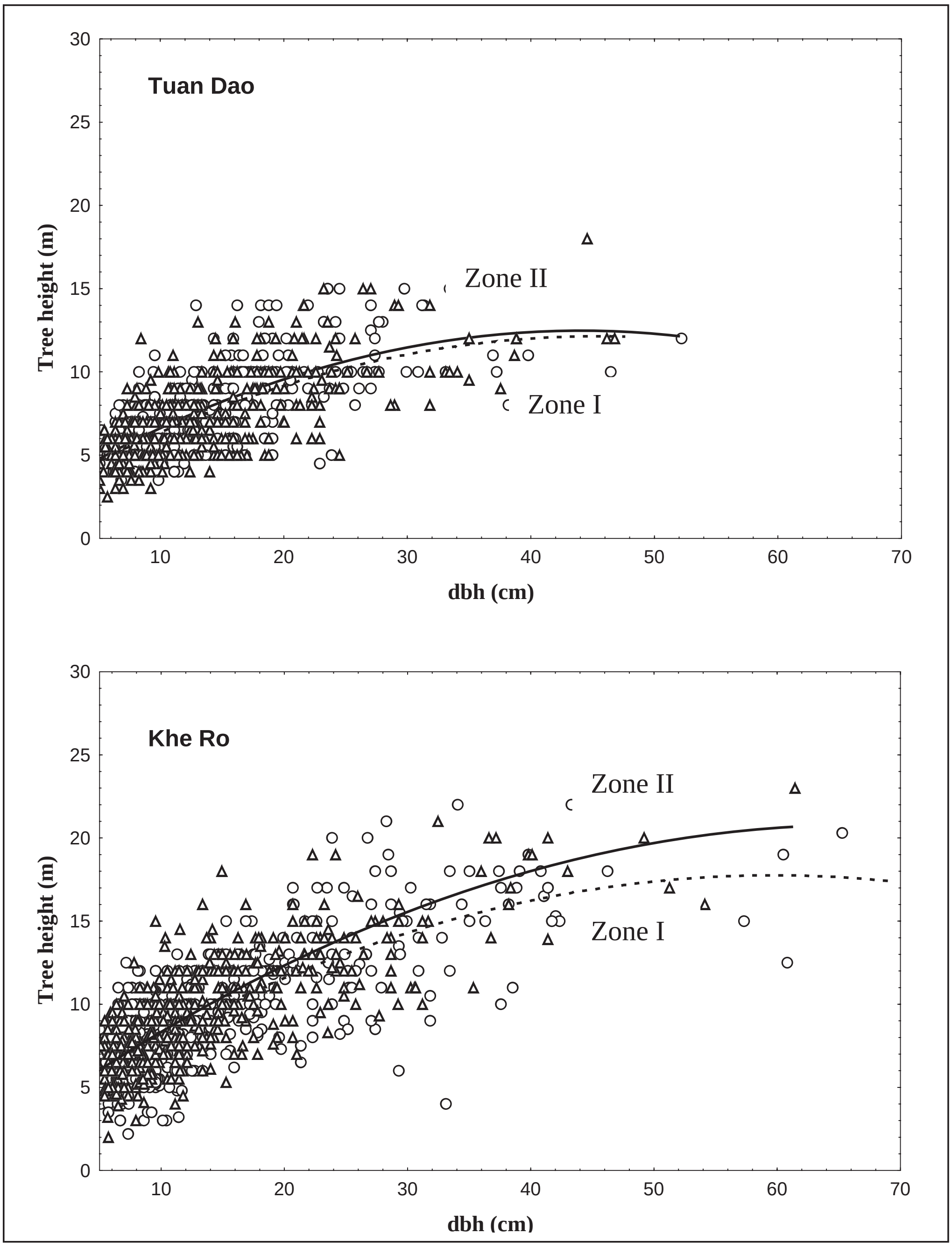

Fig. 4.11 Stand height curve in different zones of two study forest areas. Trees with dbh ≥ 5 cm. Fitted with Parabola equation (1) (PRODAN 1965).

Tuan Dao: $h_{zone\ I} = 2.6258945 + 0.4190474 \cdot d - 0{,}0046186 \cdot d^2$, r = 0.71

$h_{zone\ II} = 2.6596335 + 0.4460389 \cdot d - 0.0050697 \cdot d^2$, r = 0.71

Khe Ro: $h_{zone\ I} = 3.569409 + 0.5152196 \cdot d - 0.0038535 \cdot d^2$, r = 0.78

$h_{zone\ II} = 3.798601 + 0.4673746 \cdot d - 0.0039132 \cdot d^2$, r = 0.56

Similar to the stand height curves, height curves in different zones of both study sites are best fitted with a parabolic equation. In the zone II of Khe Ro, the R value for the diameter–height relationship (0.56) is much lower than that in zone I (0.78). Those values are similar for Tuan Dao zones I and II. Also, the parabolic model was best fitted with highest coefficient of correlation (see fig.4.11).

4.6.2 Stand height

Stand height is a useful variable for determining the site index of a stand, calculating the stand volume, predicting the future growth from stand characteristics, and evaluating silvicultutral trials (Van LAAR and AKCA 1997). For the stand height, mean height, stand height curve, and top height are the parameters which should be considered.

Mean height

The mean height of a stand is a stand feature used for accessing and estimating stand growth and is needed to estimate volume (KRAMER and AKCA 1995). In practice, it is commonly accepted that diameter and height growth are response variables. Therefore the arithmetic mean height ($\bar{h}$) is mostly used for young stands, where it is still unproblematic. However, the other mean stand height estimator, namely LOREY´s mean height, which is indirectly estimated through the height-diameter relation, is much more predominant.

LOREY´s mean height is a weighted mean height that is computed with the individual trees being weighted proportionally to their basal area as follows (PRODAN 1965, KRAMER and AKCA 1995, Van LAAR and AKCA 1997):

$$h_L = \frac{\sum_{i=1}^{k} n_i \cdot g_i \cdot h_i}{\sum_{i=1}^{k} n_i \cdot g_i} \qquad (4.12)$$

where n_i number of trees in the diameter class i
g_i the corresponding basal area for the diameter class i
h_i mean height for the diameter class i
k number of diameter class

Up to now the LOREY´s mean height is often used as an input for most yield tables and the height does not deviate among trees with mean basal areas (KRAMER and AKCA 1995). Therefore, this mean height is chosen to calculate the mean height for the present study.

Table 4.20 The arithmetic mean height ($\bar{h} \pm S_h$), standard deviation (S_h) and LOREY´s mean height (h_L) of two secondary riparian forests, Tuan Dao and Khe Ro, NE Vietnam. All trees ≥ 5 cm dbh.

Site	h_L (m)	$\bar{h} \pm S_h$ (m)
Tuan Dao	9.5	7.5 ± 2.6
Zone I	9.3	7.4 ± 2.6
Zone II	9.5	7.7 ± 2.6
Khe Ro	13.1	9.4 ± 3.5
Zone I	13.1	9.3 ± 3.6
Zone II	12.8	9.5 ± 3.3

In table 4.20, the arithmetic mean height ($\bar{h}$) is distinctly lower than LOREY´s mean height (h_L). It is in agreement with PRODAN (1965) that $\bar{h}$ is often lower than h_L. Moreover, in Khe Ro, the mean stand height is higher than that of Tuan Dao. The mean heights of different zones show very little variation. Tuan Dao has a higher mean height in zone II, whereas in Khe Ro the mean height of zone I is higher.

<u>Top height</u>

Top height is regarded as a criterion for growth prediction (Van LAAR and AKCA 1997). In modern yield tables, the estimated top height of a stand is less sensitive to thinning and more suitable for predicting the site index. After KRAMER and AKCA (1995), top height can be more precisely and easily calculated than mean stand height. The latter is more sensitive to an arithmetic shift and difficult to estimate, especially in such young and dense stands.

The WEISE´s top height (h_0) is defined as the mean height of the 20 % thickest stems of the stand (LOETSCH et al. 1973). For the strongest trees, which are biologically of greater importance than other tree classes, h_0 can be used more effectively than mean stand height for measuring stand productivity. MITSCHERLICH (1957) introduced another approach to determine top height ($\bar{h}_{100}$). $\bar{h}_{100}$ is defined as the mean height of the 100 thickest trees per hectare. The rank of h_0, $\bar{h}_{100}$ depends on stem number and the age of the stand (KRAMER and AKCA 1995).

Table 4.21 WEISE´s top height (h_0) and MITSCHERLICH´s top height ($\bar{h}_{100}$) of two natural secondary riparian forests, Tuan Dao and Khe Ro, NE Vietnam. All trees ≥ 5 cm dbh.

Site	h_0 (m)	$\bar{h}_{100}$ (m)
<u>Tuan Dao</u>	10.8	11.1
Zone I	10.4	10.2
Zone II	10.7	10.4
<u>Khe Ro</u>	13.8	15.0
Zone I	14.1	14.1
Zone II	13.5	13.4

Comparing the results of table 4.20 and 4.21, it can be found that the top heights (h_0, $\bar{h}_{100}$) of both sites are higher than mean heights (h_L and $\bar{h}$). The hilly topography with a slope of up to 45° at Tuan Dao can be a reason for higher stand heights in zone II than in zone I. Conversely, in Khe Ro, which has relative flat topography in the riparian forest areas, the stand heights of zone I are higher than those of zone II.

4.6.3 Vertical distributions

Following the IUFRO system of classification, the stand vertical distribution is presented in three strata based on the top height: upper storey (US) (tree height ≥ 2/3 of the top height), middle storey (MS) (< 2/3 and ≥ 1/3 of the top height), and lower storey (LS) (< 1/3 of top height) (LEIBUNDGUT 1958). Here, the WEISE´s top height (h_0), which was calculated as the mean height of 20 % thickest stems of the stand, is used for the classification. The top heights are accordingly 10.8 m for Tuan Dao (I) and 13.8 m for Khe Ro (II) (see 4.5.2). The results of vertical distribution of the investigated sites are accordingly summarized in table 4.22.

Table 4.22 Abundance, number of tree species, and ratios of individuals to species in different stories of two secondary riparian forests, Tuan Dao (I) and Khe Ro (II), NE Vietnam. All woody tree species per hectare.

Site	Storey	Abundance		Number of species (n)	Ratio of individuals/ species
		N/ha	%		
I	LS	6984	90.1	89	1:79
	MS	430	5.5	72	1:6
	US	346	4.4	66	1:5
II	LS	9259	90.8	112	1:83
	MS	517	5.1	93	1:6
	US	427	4.2	79	1:5

Notes: LS= Lower storey; MS=Middle storey; US= upper storey

It can be seen in table 4.22 that the highest stem numbers per hectare are found in the lower storey (90.1-90.8 %). The upper storey has the lowest stems, approximately 4 % and followed by the middle storey with 5.1-5.5 %. Similar trends have been found for natural tropical forests in Columbia (FÖRSTER 1973), N Madagascar (LOPEZ 2003) and N Ethiopia (GEBREHIWOT 2003).

After LAMPRECHT (1969) the normal ratios vary between 1:5 and 1:10 in tropical forests. NGUYEN (2000) found mixing ratios between 1:2 and 1:6 for the trees ≥ 10 cm dbh in different secondary forest successions in N Vietnam. The ratios of individuals per species are approximately equal between two sites; however, there are strong variations among the three strata. In the middle and upper stories, for example, only 5-6 stems were found per species. This is evidence of the intensive mixture in these strata. Conversely, the ratios of individuals per species reach 1:83 in the lower storey of study sites. The higher individuals per species in the lower storey may be given a potential source of regeneration for stand conservation. For sustainable long term silvicultural management, one should focus on the abundance of potential crop tree species of the stands.

Table 4.23 Number of tree species occurring in different forest stories of two secondary riparian forests, Tuan Dao (I) and Khe Ro (II), NE Vietnam.

Site	Number of tree species occurring in						
	only US	US+MS	US+MS+LS	US+LS	only MS	MS+LS	only LS
I	9	7	44	8	12	3	28
II	16	9	46	3	15	19	41

Notes: Only US = species which occurred only in the upper storey; US+MS = species which occurred in upper and middle stories; US+MS+LS = species which occurred in all stories; US+LS = species which occurred in the upper and lower stories; only MS = species which occurred in the middle storey only; MS+LS = species which occurred in the middle and lower stories; only LS = species which occurred in the lower storey only.

Nearly half of the total number of species (40 - 48 %) in all stories in both sites were species with a regular vertical distribution as described in LAMPRECHT (1989) (see tab. 4.23). It can be assumed that these species in their respective stands have no problem regenerating. The numerous tree species (30 - 35 %) are limited to the lower strata and obviously yet unable to reach the upper storey, which indicates the poor quality of their regeneration.

Hence, the presence of the potential commercial tree species and their respective abundances are considered to be crucial conditions for continuity of regeneration. For instance, despite their occurence in all stories of the site Tuan Dao, tree species like *Erythrophloeum fordii*, *Madhuca pasqieri*, *Vatica tonkinensis, Lithocarpus ducampii, Machilus odoratissima*, *Ixonanthes cochinchinensis*, *Canarium album*, *Canarium tonkinensis, Mischocarpus oppositifolius* and *Pygeum arboreum*, made up only 9.3 % in the lower storey compared with 22% in the upper storey and 32 % in the middle storey. In Khe Ro, 47 % of trees in the upper storey and 23 % of trees in the middle storey belong to the potential economical species like *Erythrophloeum fordii*, *Madhuca pasqieri*, *Vatica tonkinensis, Lithocarpus ducampii, Machilus odoratissima, Ixonanthes cochinchinensis, Canarium album, Pelthophorum tonkinensis, Pithecellobium clypearia, Castanopsis indica* and *Pygeum arboreum*, whereas they make up only ca. 7% in the lower strata. This reveals a noticeable difficulty for the sustainable continuity of these species in the stands.

4.7 Estimated volumes and biomass

Estimation of stand volumes is essential for effective forest production management. The estimation will assist in the determination of potential product harvests, but may also incorporate information about harvesting practice if harvestable volume is used (SPURR 1952, BRACK 1999). There are two general approaches to the estimation of stand volume in use today, called the volume tables and the sample tree approach. For the investigated sites and tree species there is no developed volume table, thus the following function was used to compute the volume of stands as well as of potential timber tree species:

$$v = g \cdot h \cdot f \qquad (4.13)$$

where v = volume
g = basal area.
h = total height.
f = form factor. A form factor of 0.5 is commonly used for uneven-aged mixed stands in the tropics (WHITMORE 1984)

To estimate the total stand volume (v_t), all tree with dbh ≥ 5 cm are included. Accordingly, the volume of potential timber trees (v_{po}) was computed for trees with the development tendency classes 1 in the stands (see 3.2.1).

In the present study, due to the protection functions of the stands, there is an increased interest in measuring biological productivity in terms of the above-ground biomass. On the basis of the total volume of the stand, the above-ground biomass of the stand can be estimated accordingly with the following function:

$$Ba = v_t \cdot r \qquad (4.14)$$

where B_a is above ground biomass, v_t is volume of the above ground trees and r is basic wood density of timber. The specific gravity commonly gives a mean value of 0.6 g/cm^3, i.e. 0.6 ton/m^3 (CHUDNOFF 1976, WHITMORE 1984). It is certainly less than 0.6 for a forest dominated by pioneer trees. For the study sites, the stand volumes, volume of logged stems, volume of the potential and the above ground biomass are summarized in table 4.24.

Table 4.24 Estimated stand volume (v_t), logged volume (v_l), volume of potential crop trees (v_{po}), and above ground biomass (B_a) in the study stands, NE Vietnam. All trees ≥ 5 cm dbh. Zone I: 1-25 m from the riverbank; zone II: 25-50 m from the river bank.

Site	v_t (m^3/ha)	v_l (m^3/ha)	v_{po} (m^3/ha)	B_a (ton/ha)
Tuan Dao	76.5	36.1	43.3	45.9
Zone I	80.9	37.8	45.4	48.5
Zone II	72.3	34.3	41.2	43.4
Khe Ro	147.7	78.7	110.2	88.6
Zone I	168.3	89.2	124.5	100.9
Zone II	127.1	68.6	95.3	76.3

As given in the table 4.24, the total stand volume of the study sites ranges from 76.5 to 147.7 m^3/ha. 57–75 % is considered to be the volume of potential species or commercial species, which were classified as social ascendancy (see 3.2.1). Correspondingly, the above ground biomass of trees with dbh ≥ 5 cm at the Khe Ro site is obviously higher than that at the Tuan Dao site. In the zone I of both sites, all parameters are higher than those of zone II. It can be assumed that the forest productivity of Khe Ro are distinctly higher than those in Tuan Dao. The values v_t, v_{po} and B_a in Khe Ro are around double the values of those in Tuan Dao (see table 4.18). The intensive human impact through long-time intensive logging on the Tuan Dao forest led to reducing number, volume, and quality of timber products. Moreover, the regular exploitation of bamboos accompanied with its destruction due to transport might be a cause of degrading timber resources in this stand. Period flooding in zone I could be a reason for higher volumes and biomass.

In Asian evergreen moist forests, WHITMORE (1975) found that the average growing stock for tree diameters > 10 cm was 135 m^3 ha^{-1} and the volume of extraction between 20 and 100 m^3 ha^{-1}. A total standing volume of more than 829 m^3/ha was estimated by

RICHTER (1998) for trees with dbh > 10 cm in a riparian forest of East Kalimantan, Indonesia. Of that, approx. 72 % was considered potential log volume. In Son Dong district, an average timber volume between 45 and 94 m^3/ha was expected for the medium and poor forest categories (IIIa2 and IIIa1) to which the researched sites belong (ANONYMOUS 1997).

4.8 The dynamics of woody understorey regeneration

The natural regeneration data were collected along different riparian strips of the study sites. Apart from vegetation like bamboos, lianas, *Macaranga denticulate* and other shrubs (vide chapter 4.5.3), the data for woody regeneration were enumerated into two separated classes. Class A included the newly emerging seedlings (juveniles) with height $\leq$ 30 cm and class B included established seedlings (saplings) with height from 31 cm to 1.3 m and dbh < 5 cm.

The diversity of regeneration as well as the proportion of saplings to seedlings introduced by FELFILI (1997), at both sites are summarized in table 4.25.

Table 4.25 Density of regeneration per hectare and ratios of saplings to seedlings in two riparian forest sites in Tuan Dao and Khe Ro, NE Vietnam. All trees < 5cm dbh.

Site	Density of regeneration (N/ha)			Ratio of saplings/seedlings
	Total	Juveniles	Saplings	
Tuan Dao	6,972 $\pm$ 792.4	3,000	3,972	1.3:1
Khe Ro	9,236 $\pm$ 943.2	5,588	3,648	0.7:1

The ranges of juvenile and sapling densities were 3,000-5,588 ha^{-1} and 3,648-3,972 ha^{-1}. A clear difference in density of total regeneration was found between the two sites. In the case of juveniles, dissimilarities in number are markedly higher in Khe Ro, but there was no statistically significant difference in density of saplings. Comparable results for regeneration density have been documented in tropical natural secondary forest areas in Kalimantan, Indonesia (OTSAMO 2000), in Myanmar (KYAW 2003), and in N Ethiopia (GEBREHIWOT 2004). The regeneration (trees with dbh < 5 cm) of the gallery forest at the Córrego dos Macacos (Brazil) gave 2,361 individuals ha^{-1} (PAULA et al. 1996). However, an absolute higher density of regeneration was found in tropical gallery forests of Brazil. A range from 25,605 to 41,092 individuals/ha were estimated from a regular observation within a period of five-year between 1986 to1991 (FELFILI 1997).

Selective logging, which was commonly used in both areas, is likely to destroy all regeneration on the skid trails, and most saplings in gaps (JONKERS 1987). As a consequence of regular human impact to the Tuan Dao forest by cutting down a great number of important mother trees or through logging damage, the proportion of saplings to seedlings was high (1.3:1), whereas in Khe Ro, this ratio was 0.6:1. Here, the local light conditions possibly also play a decisive role for successful establishment of light-demanding species. Moreover, periodic flooding of the study areas, especially in the inundated zones, may pose a serious obstacle to the survival and establishment of seedlings by juveniles. In Tuan Dao, the higher light gaps due to felling activities give an explanation for the higher ratio of saplings to seedlings, and for the fact that the light-demanding species are over-represented in the number of saplings. It indicates, however, a lack of seedling source for further development of this stand.

The changes in total abundance of regeneration, juveniles, and saplings were evaluated using a series of subplots located at different distances from the river (1-5m, 10-15 m, 20-25 m, 30-35 m, and 40-45 m), as already referred to in section 4.4.6. Figure 4.11 demonstrates the variation in number of seedlings, saplings, and total regeneration (trees < 5 cm)

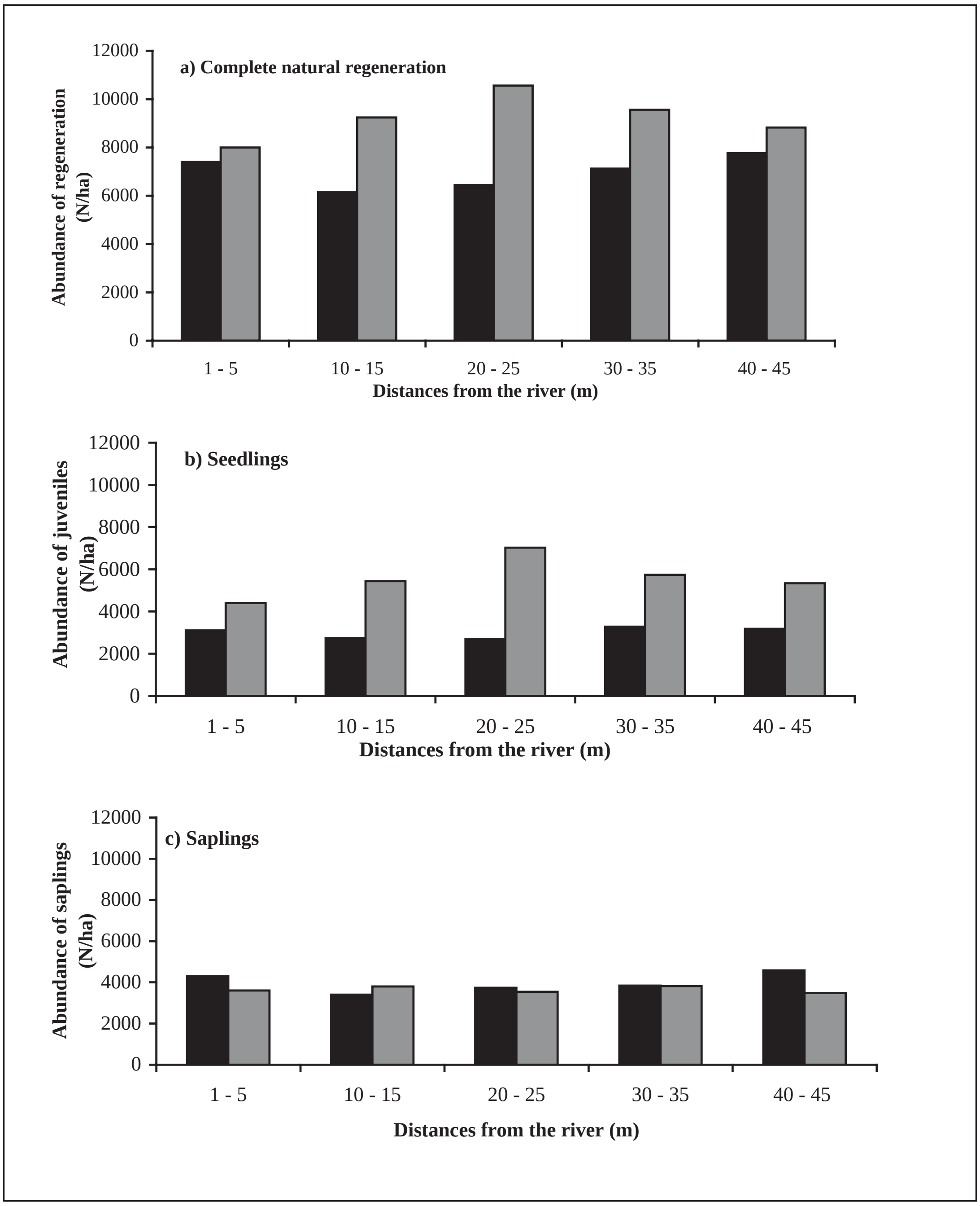

Fig. 4.12 The distribution of regeneration, juveniles and saplings at different distances from the river in Tuan Dao (black) and Khe Ro (grey), NE Vietnam. a) Total woody regeneration: trees < 5 cm dbh; b) juveniles: newly emerging seedlings (≤ 30 cm height); and c) saplings: established seedlings (between 31 and 130 cm height and dbh <5 cm).

In this study, although the abundances of regeneration, juveniles,and saplings were slightly difference at different distance from the river, as shown in figure 4.12, the number of seedlings and saplings are not significantly different (ANOVA, $p<0.05$). At the distance 1-5 m from the river of Khe Ro, there were slightly fewer seedlings and saplings. This is the opposite of the case of seedlings and saplings in Tuan Dao. The highest abundance of seedling species such as *Vatica tonkinensis* and *Pithecellobium clypearia* in Khe Ro and *Vatica tonkinensis* in Tuan Dao were concentrated mostly in some subplots.

The results of the present study show that a wide number of woody species regenerate in these riparian forests. On a 2,500 m^2 sized sample, a total of 71 woody juveniles and saplings species for Tuan Dao and 96 species for Khe Ro were recorded, respectively. This is in agreement with the results of the research that has been published in tropical natural forests in Asia. APEL (1996) found up to 143 species on 4,500 m^2 in Southwest China. In Myanmar, KYAW (2003) count up to 39 species on 4000 m^2. In Indonesia, BRODBECK (2004) recorded up to 83 species per 625 m^2 of natural forests.

Concerning the proportion of seedlings/ sapling species, which can play an important role in the stand dynamics, the abundance per ha and ratios of saplings to seedlings of each species were computed. The most common natural regeneration species are ranked by their IVI, which were calculated for trees $\geq$5cm dbh, and presented in table 4.26.

Table 4. 26 Absolute and relative abundance of juveniles and saplings of the most important species in two secondary riparian forests, Son Dong, NE Vietnam. Ranked by IVI for trees with dbh ≥5cm.

Species	Juveniles		Saplings		Ratio
	N/ha	%	N/ha	%	
Tuan Dao					
Mischocarpus oppositifolius	40	1.3	96	2.4	2.4:1
Gironniera subaequalis	54	1.8	4	0.1	0.1:1
Pygeum arboreum	46	1.5	3	0.1	0.1:1
*Vatica tonkinensis**	668	22.3	260	6.5	0.4:1
*Erythrophloeum fordii**	88	2.9	44	1.1	0.5:1
Cylindrokelupha chevalierii	92	3.1	36	0.9	0.4:1
Canarium album	52	1.7	104	2.6	2.0:1
Eurya nitida	80	2.7	344	8.7	4.3:1
Garcinia oblongifolia	96	3.2	172	4.3	1.8:1
Schima superba	12	0.4	40	1.0	3.3:1
Xylopia vielana	32	1.1	56	1.4	1.8:1
Wrightia tomentosa	8	0.3	64	1.6	8.0:1
Lithocarpus ducampii	16	0.5	36	0.9	2.3:1
Canarium tonkinensis	0	0	4	0.1	-
Machilus odoratissama	20	0.7	12	0.3	0.6:1
Other species	1,696	56.5	59	2.4	2.4:1
Total	3,000	100	3,972	100	1.3:1
Khe Ro					
*Vatica tonkinensis**	644	11.5	360	9.9	0.6:1
Engelhardta chrysolepis	44	0.8	48	1.3	1.1:1
Pithecellobium clypearia	2,600	46.5	152	4.2	0.1:1
Catanopsis indica	172	3.1	96	2.6	0.6:1
Lithocarpus ducampii	224	4.0	196	5.4	0.9:1
Maesa balansae	44	0.8	72	2.0	1.6:1
Eurya persiaefolia	148	2.6	280	7.7	1.9:1
*Erythrophloeum fordii**	116	2.1	24	0.7	0.2:1
Aporusa dioica	84	1.5	140	3.8	1.7:1
Pygeum arboreum	60	1.1	72	2.0	1.2:1
Mischocarpus oppositifolius	116	2.1	60	1.6	0.5:1
Quercus platicalyx	4	0.1	20	0.5	5.0:1
Daphniphyllum atrobadium	156	2.8	76	2.1	0.5:1
Elaeocarpus griffithii	8	0.1	20	0.5	2.5:1
Garcinia oblongifolia	88	1.6	118	3.2	1.3:1
Other species	1,080	19.3	1,914	52.5	1.8:1
Total	5,588	100	3,648	100	0.7:1

(*) = rare valuable tree species

As can be seen in table 4.26, regeneration of the pioneer species and light-demanding fast growers were mainly dominated by the sapling stage. These species included eg. *Cratoxylum pruniflorum, Phyllanthus reticulata, Canarium album,* and *Garcinia oblongifolia* in Tuan dao and *Maesa balansae, Daphniphyllum calicinum, Aporusa dioica,* and *Garcinia oblongifolia* in Khe Ro. Many of the commercial timber species like *Vatica tonkinensis, Erythrophloeum fordii, Mischocarpus oppositifolius, Lithocarpus ducampii,* and *Castanopsis indica* showed up in the group of 15 most abundant species at both sites. Their representation is in fact more or less restricted to the juvenile class. Neither seedlings nor saplings of the valuable tree species *Madhuca pasquieri* were found in Khe Ro, although this species was ranked in the top 15 of the most important tree species with dbh $\geq$ 5 cm here. Their relatively poor survival into pole and tree stages may result from their poor competitive ability as compared with that of pioneer species communities in these sites (LAMRECHT 1989, GÓMEZ-POMPA et al. 1991). It can be assumed that although both sites had adequate new regeneration in general, the poor and less valuable shade-tolerant tree species occupied the established phrase. For improvement of stand dynamics, a silvicultural approach is must be utilized to accelerate the growth of all-sized stems of valuable species through provoking natural regeneration. This includes actions such as cutting climbers and lianas, eliminating undesirable tree species or bamboos, as well as liberation of the valuable mother trees. Especially for the production forest categories of Tuan Dao, the important economic tree species, which already grow well in the areas, enrichment planting is recommended. These species include *Vatica tonkinensis*, *Erythrophloeum fordii, Mischocarpus oppositifolius, Lithocarpus ducampii, Castanopsis indica*. *Madhuca pasquieri* and *Canarium sp.* With this silvicultural treatment, the quality of the production forest stand will gradually be improved by planting the commercial and ecological tree species.

4.8 Tree ring analysis

4.8.1 Relation between tree growth and precipitation

Tree ring analysis serves as a tool for describing and interpreting the stand dynamics and development of temperate forests. Tree ring analysis of habitats along rivers can be used for reconstructing site characteristics and palaeohydrological dynamics (SCHWEINGRUBER 1996, WORBES 1996, 2003). The primary problem in tropical tree-ring analysis is the frequent lack of well defined cyclical growth rings, since trees grow continuously throughout the year and as a consequence often lack the annual growth rings (JACOBY 1989, WHITMORE 1990, VETTER and WIMMER 1999, BAATTACHARYYA et al. 1992). Until recently many dendrochronologists were still pessimistic about tropical tree-ring analysis due to indistinct ring anatomy, the possible formation of false rings in tropical trees, and a lack of awareness of successful early work in tropical tree-ring analysis (JACOBY 1989, BAATTACHARYYA et al. 1992). The existence of annual growth rings in the tropics was pointed out and used for growth estimation by BRANDIS (1898). Several successful research efforts in tree-ring studies successfully identified annual growth rings in many tropical tree species from South East Asia, Africa, and Latin America (COSTER 1927, 1928, BERLAGE 1931, MARIAUX 1967, 1969, WORBES 1985, 1989). Using tree-ring analysis to study climate and tree growth relationships has gained more and more interest and become in recent years the subject of several international meetings (VETTER and WIMMER 1999).

The existence of a dry season with average precipitation less than 60 mm per month may play a role in growth periodicity in the region, due to the decrease in soil water potential. This may lead to the formation of boundaries in the wood resulting from cambial dormancy (FRANCO 1979, WORBES 1995). In the present study sites, the climate condition is characterised by monsoon influence with a dry season from November to February. This seasonal monsoonal rainfall can be regarded as a basis for analysing tree-ring analysis. Nevertheless, the young forest state and low species abundance in such diverse stands is a problem for tree-ring studies. In Tuan Dao, 40 trees of *Erythrophloeum fordii, Lithocarpus ducampii, Mischocarpus oppositifolius* and

Pygeum arboreum, and 30 trees of *Erythrophloeum fordii, Catanopsis indica* and *Pygeum arboreum* from Khe Ro were sampled.

For regression analysis, the measured tree-ring width series were first cross-dated to avoid errors due to counting and mistakes resulting from misidentification of ring features or ring absence, as well as to compare the ring-width curves from different individuals in matching ring-width patterns for a species or a region (FRITTS 1976, RINN 1996). To obtain a mean curve for a tree species or site, the individual ring-width curve was transformed into indexed curves in order to scale the normal distribution of the values (COOK and BRIFFA 1990, RINN 1996, SCHÖNGART 2003).

Precipitation is generally considered to be a decisive factor for diversity in the tropical forests and it is important to investigate the influence of this factor on tree growth. The precipitation of different time series: 1) Annual precipitation "Annualprec."; 2) Precipitation in the rainy season (March to October) "Rainyprec.", and 3) Precipitation in the dry season (November to February) "Dryprec." were calculated and correlated with standardized tree ring mean curves.

For comparison between ring-width indices and precipitation curves, it is required to calculate the t-value, the percentage of parallel variation (Gleichläufigkeitsprozent, Glk.). Percentage of parallel variation is known as the percentage of slope (interval trend) equivalent of two series (RINN 1996). Generally, matches are expected to have a Glk in of more than 55% or 60 %. The indexations as well as the computation of t-value and Glk-value were operated with TSAP and Statistica software. The results from regression analysis are presented in table 4.27 and 4.28.

Table 4.27 Correlation between tree-ring width indices and precipitation in Tuan Dao forest, NE Vietnam. Denoted by t-value and "*Gleichläufigkeit*" value (Glk.). *Lithocarpus ducampii* (1), *Erythrophloeum fordii* (2), *Pygeum arboreum* (3), and *Mischocarpus oppositifolius* (4).

Sum of precipitation	1		2		3		4	
	Glk.(%)	R	Glk.(%)	R	Glk.(%)	R	Glk.(%)	**R**
Annual	66.2	0.37 *	62.9	0.34*	70.0	0.51 *	70.0	0.43 *
Rainy season	61.2	0.39 *	62.9	0.36 *	60.0	0.37 *	67.5	0.35 *
Dry season	55.0	0.02	44.3	0.23	51.2	0.17	56.2	0.21

(*) = *significant correlation at the 95 % confidence level*

Table 4.28 Correlation between tree-ring width indices and precipitation in Khero forest. NE Vietnam. Denoted by t-value and "*Gleichläufigkeit*" value (Glk.). *Catanopsis indica* (1), *Erythrophloeum fordii* (2) and *Pygeum arboreum* (3).

Sum of precipitation	1		2		3	
	Glk.(%)	R	Glk.(%)	R	Glk.(%)	R
Annual	67.5	0.38 *	70.0	0.44*	65.7	0.32 *
Rainy season	65.0	0.32 *	70.0	0.37 *	68.6	0.19
Dry season	43.8	0.11	51.2	0.16	55.7	0.03

(*) = *significant correlation at the 95 % confidence level*

As can be seen in table 4.27 and 4.28, in both study areas the annual ring indices of all tree species showed a significant positive correlation with the total amount of precipitation over the year as well as with the total precipitation in the rainy season (March to October). The parallel variation values (Glk. in %), as a measure for the similarity of two chronologies, are in all cases comparably high in the rainy period and over the year, being > 60%. However, the correlation analysis between tree-ring width series and total precipitation in the dry season does not give significant coefficients. In the dry period, the Glk-value of species and precipitation series from two sites are all lower than 60%, *Castanopsis indica* of Khe Ro only has the Glk-value 43.8 % when crossdated with precipitation series. The mean curve indices of *Erythrophloeum fordii* in Khe Ro and *Pygeum arboreum* in Tuan Dao correlated highest with the annual precipitation series (0.44 and 0.51); the Glk.-values in these cases are 70 %. Therefore, it can be assumed that the sampled species showed some amount of growth periodicity in the rainy season, although they were marked as species which continuously grow throughout the year.

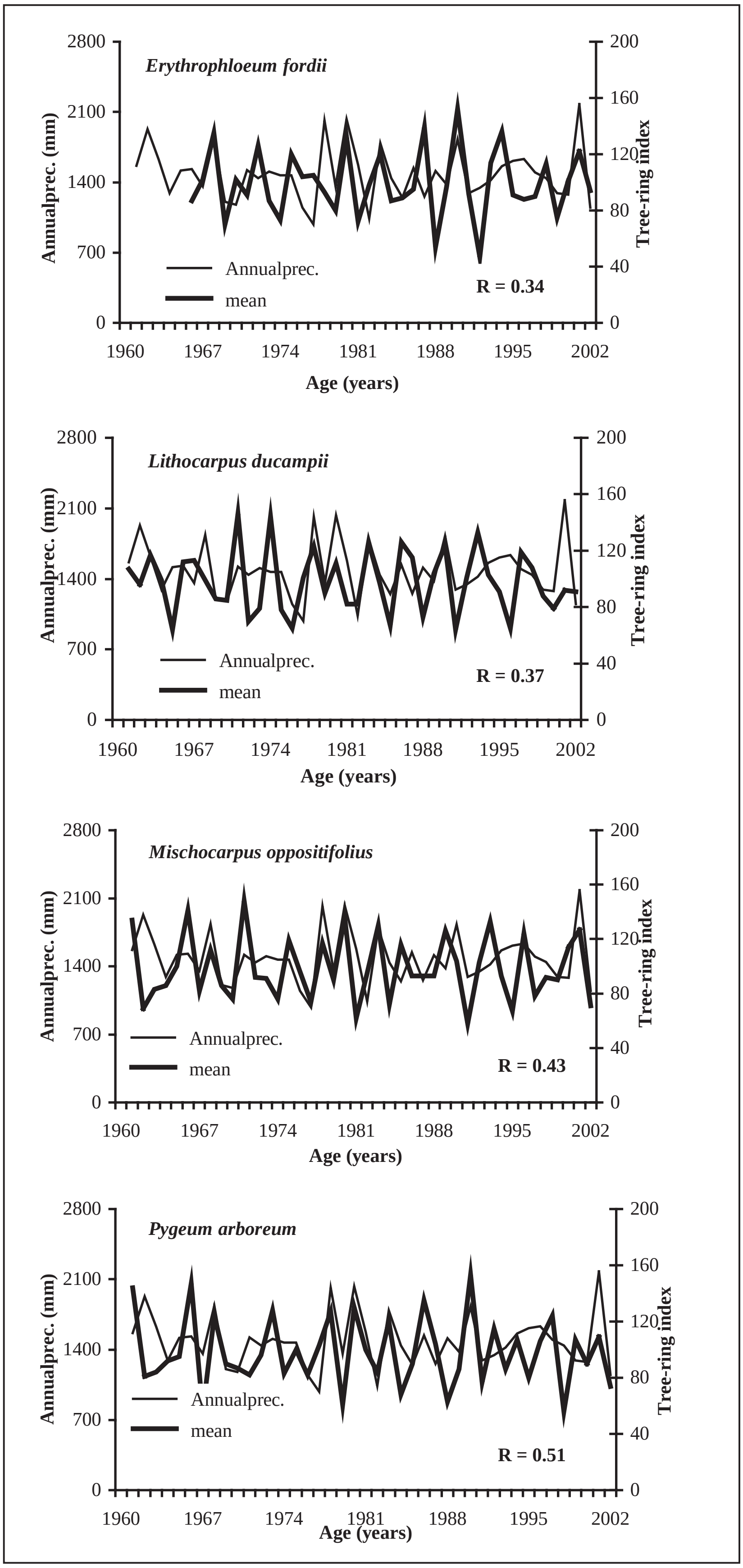

Fig. 4.13 Mean ring-width indices (mean) and annual precipitation (Annualprec.) of four tree species in Tuan Dao forest, NE Vietnam.

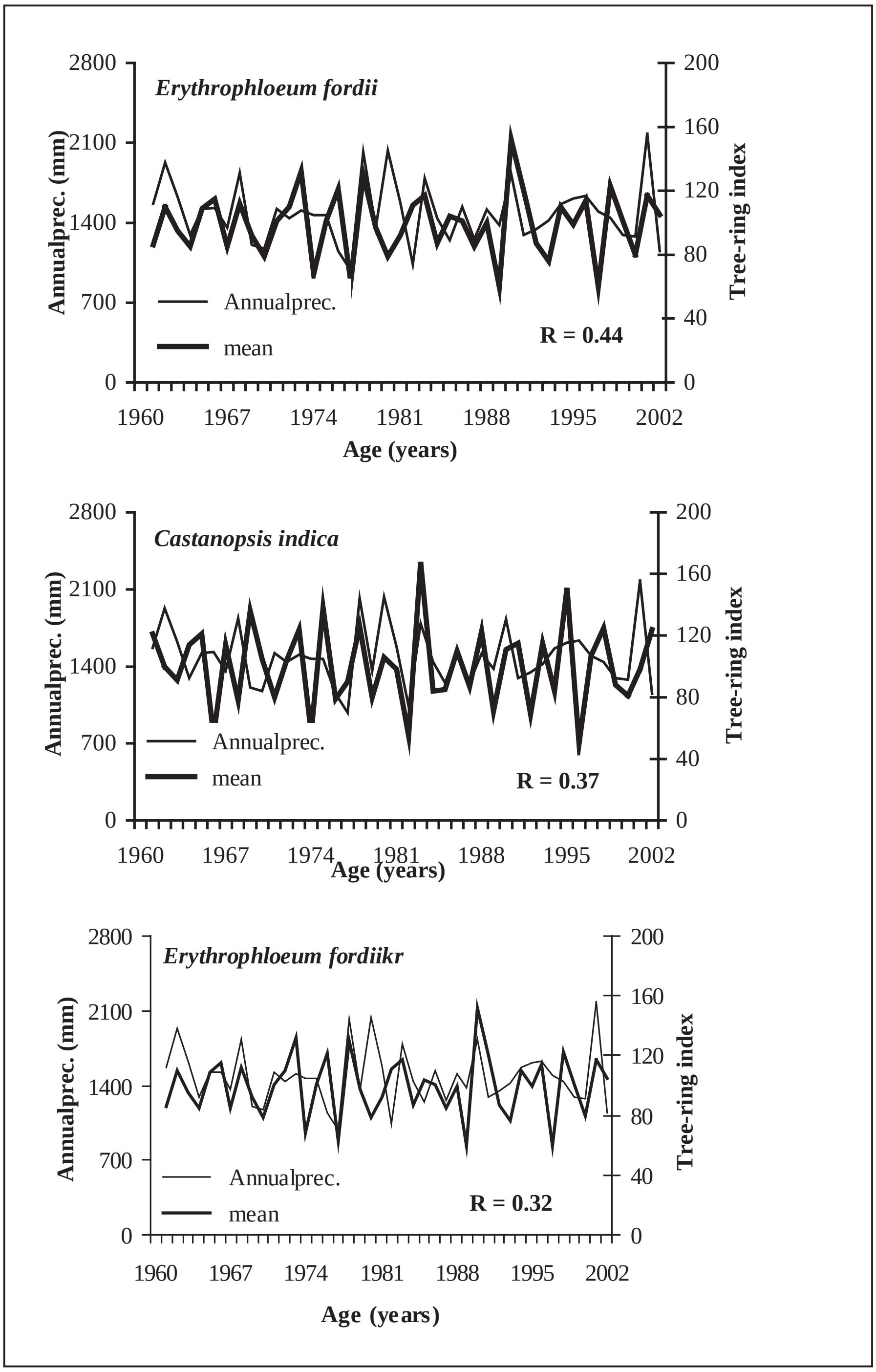

Fig. 4.14 Mean ring-width indices (mean) and annual precipitation (Annualprec.) of three tree species in Khe Ro forest, NE Vietnam.

The ring-width series were found to correlate with different time periods over the year. FRITT (1976) found that variations in monthly precipitation are most commonly directly correlated with ring widths in trees on semiarid sites. Within the tropics, significant correlations between tree ring chronologies with precipitation in different time periods have been documented. WORBES (1999) assumed from a climatological analysis of the tree-ring chronologies that tropical tree species from the Caparo Forest Reserve in Venezuela were influenced by precipitation of different periods. For example, rings found in *Swietenia macrophylla*, *Pterocarpus vernalis* and *Pinus caribaea* correlated most highly with the extended dry period (November-April), whereas *Cedrela odorata*, *Tectona grandis* and *Terminalia guianensis* showed significant correlation with the precipitation from the rainy season. From research in South East Asia, PUMIJUNGNONG (1999) showed that Teak growth was mainly driven by the late rainy season. Rings in teak from Myanmar was found to be significantly correlated with the precipitation of the rainy season (KYAW 2003). BAATTACHARYYA et al. (1992) reported the correlation between tree growth of *Cedrela toona* and annual rainfall as well as between Teak growth and the sum of rainfall in the dry season.

4.8.2 Tree growth dynamics

4.8.2.1 Diameter growth

Tree growth dynamics deal with the increase of tree size with time, which includes the increment of diameter, height, basal area, and volume (LU 1999). Tree growth data are important criteria for evaluating site quality and growth performance of the tree species, as well as for developing silvicultural and management systems for the forest stands (ZUHAIDI et al. 1994). However, the growth rates of tropical trees under natural condition are difficult to assess, because of the multitude of species and constantly changing pattern of competition (WORBES 2003). Tree growth rates were calculated from repeated diameter measurements by means of statistical methods (LIEBERMANN et al. 1985). The lack of preliminary information about the stand and stand dynamics can potentially be compensated be using the measured tree-ring width series to estimate the growth trends of researched species in the area. This estimation can be used to model long-term growth for each study site. The dendrochrological data of investigated species and stands are summarised in table 4.29.

Table 4.29 Dendrochronological data for four investigated tree species from Tuan Dao and three species from Khe Ro, NE Vietnam.

Species	Tree samples (n)	dbh (cm)	Mean age (years)	Time span	Radial increment (cm/year)
Tuan Dao					
Erythrophloeum fordii	10	22.5-33.1	38	1948-2002	0.31 ± 0.19
Pygeum arboreum	12	19.1-31.8	40	1948-2002	0.27 ± 0.14
Lithocarpus ducampii	10	18.5-51.6	43	1945-2002	0.34 ± 0.16
Mischocarpus oppositifolius	11	26.6-46.2	52	1929-2002	0.29 ± 0.22
Khe Ro					
Erythrophloeum fordii	10	21.0-38.4	48	1914-2002	0.27 ± 0.13
Pygeum arboreum	10	17.2-33.4	42	1913-2002	0.27 ± 0.19
Castanopsis indica	10	19.1-41.4	41	1940-2002	0.29 ± 0.19

As can be seen in table 4.29, tree species in Khe Ro are older than those in Tuan Dao. Hence, there are variations in growth rates within species and between species.

The age-diameter relationship is very variable and generally poor in natural tropical forests and there is a high variation of growth rates even within the same diameter class. For the study sites, the relationship between diameter and age was estimated by multi-regression for all the dated trees. A weak significant correlation was found between age and dbh, with correlation coefficients (r) of 0.38 in Tuan Dao and 0.58 in Khe Ro. Within a species, the age-diameter increment relationship was demonstrated through the cumulative annual diameter growth curves, which were assumed from all measured tree ring-widths and regression analysis for each species. The mean curve of each species was fitted with an exponential function (see figure 4.15).

As is shown in table 4.29 and figure 4.15, the mean annual growth rates differ from species to species and in both sites. In Khe Ro, the mean ring-widths vary between 4.8 mm $year^{-1}$ in *Pygeum arboreum* and 0.58 cm $year^{-1}$ in *Castanopsis indica*. Tree species of Tuan Dao show higher annual increment, with 0.52 cm $year^{-1}$ in *Pygeum arboreum* and 0.68 cm $year^{-1}$ in *Lithocarpus ducampii*. Although trees in Tuan Dao show higher mean annual growth rates than those in Khe Ro at early stages, later they tend to level off distinctly. The diameter growth curves of *Lithocarpus ducampii* and *Castanopsis indica*, which belong to the dominant fast growth family in the region (Fagaceae), show the steepest tendencies. These may be the result of prevailing species characteristics, light and soil conditions. The Khe Ro forests have higher stand densities that may be a disadvantage for the initial growth of trees. While the Tuan Dao stand has more openings from previous bamboo and timber exploitation, this site’s good soil conditions are expected to improve the growth condition of the remaining trees.

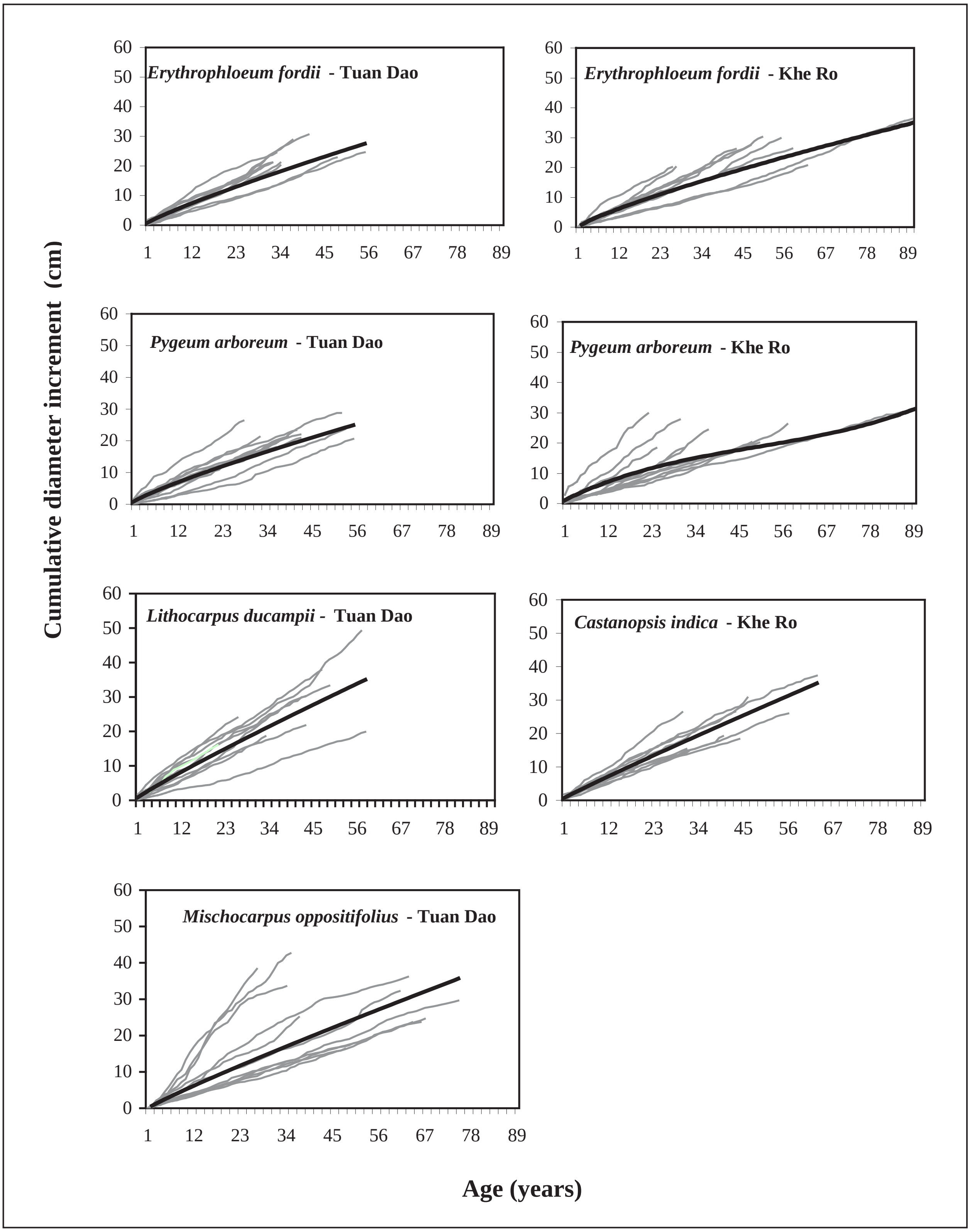

Fig. 4.15 Individual (grey) and fitted mean (black) cumulative diameter increment curves of four important economic tree species in Tuan Dao (left) and three important economic tree species in Khe Ro (right).

The diameter increment growth rates of the present study are relatively comparable with the results from other growth rate estimations in the tropics. MANOKARAN and KCHUMEN (1987) estimated a mean radial increment of 0.26 cm year^{-1} for all species in a Malaysian Dipterocarp forest. Based on 3 years observation in the mixed tropical rain forest in Xishuangbana of China, LU (1999) calculated an annual diameter increment (*Id*) up to 0.7 cm year^{-1}, where the *Id* of Fagaceae amount to 0.67 cm year^{-1}. WORBES (2003) found considerable diameter growth rates among different forest stories. The lowest values showed that species of the lower storey (0.20-0.58 cm year^{-1}) and the tree species in the other storeys had the highest growth rates (0.36-0.82 cm year^{-1}). SCHÖNGART (2003) indicated that tree species in the inundation forest in Central Amazon showed different growth trends in diameter. The pioneer species had very high growth rates in the young stage; however, this reduces sharply with increasing age. The tree species in the late secondary succession stage grow generally slow. That is also shown in the growth trends of individual tree species in the study, whereby the early years make up the steeper parts of the growth curves.

To gain an overview of the diameter growth used for forest management practices, the fitted mean curves of tree species were assumed for each study site (see fig. 4.16). The investigated tree species belong to wood groups III to VI, which means that the legal minimum harvestable diameter (MHD) is 35 cm. Only *Erythrophloeum fordii* belongs to wood group II, with a MHD of 45 cm (ANONYMOUS 1995). In order to reach the MHD, species require different lengths of time.

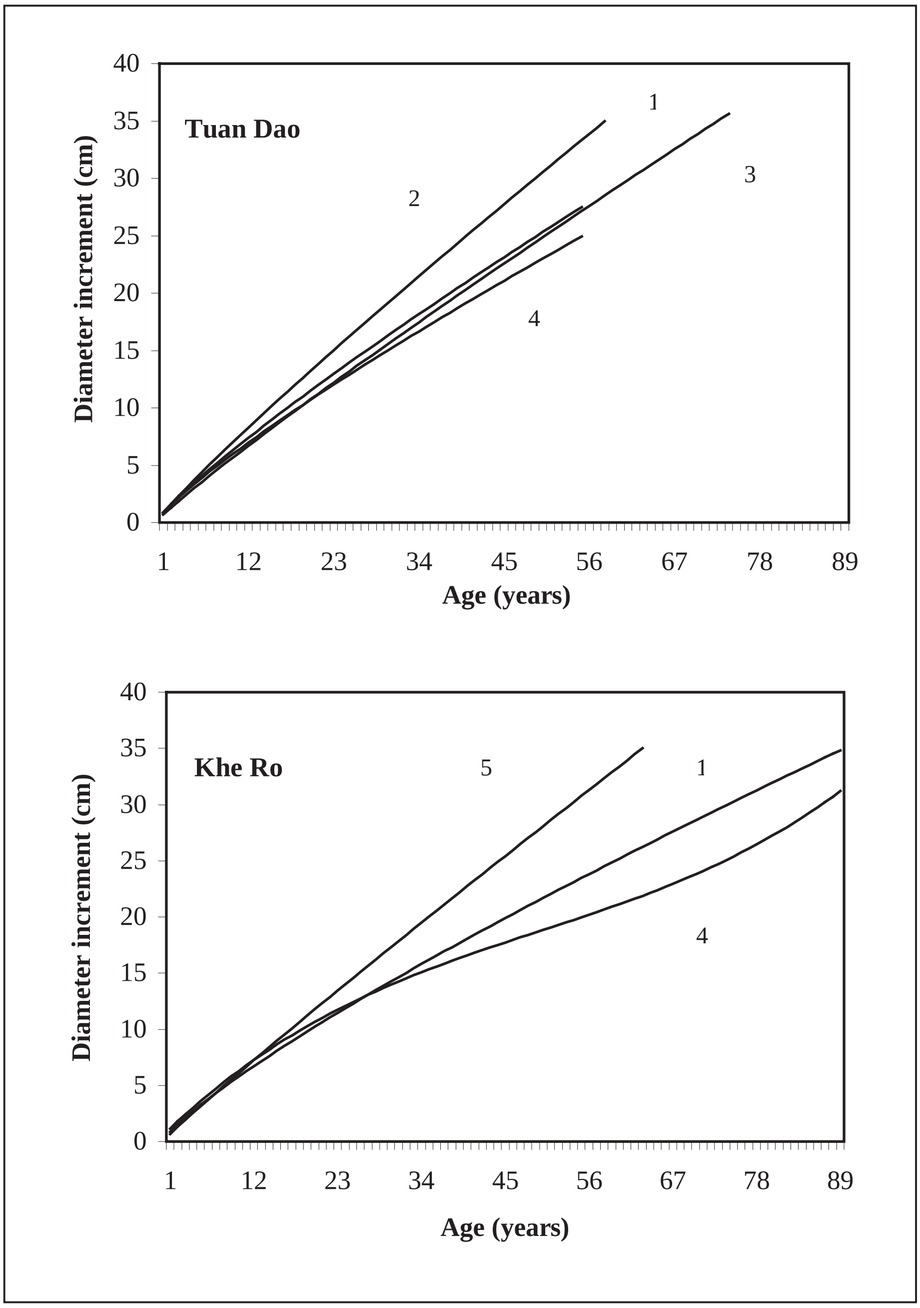

Fig. 4.16 Fitted mean cumulative diameter growth curves of different tree species of Tuan Dao and Khe Ro and the time estimates to reach legal minimum harvestable diameter (MHD).

1: *Erythrophloeum fordii*; 2: *Lithocarpus ducampii*; 3: *Mischocarpus oppositifolius*; 4: *Pygeum arboreum*; 5: *Castanopsis indica*.

The present study results show that the fastest growing species have diameter growth between 0.58 cm year^{-1} (*Castanopsis indica* of Khe Ro) and 0.68 cm year^{-1} (*Lithocarpus* *ducampii* of Tuan Dao), reaching a MHD of 35 cm between 55 and 60 years.The remaining species need much more time to grow into this MHD: for example, *Erythrophloeum fordii* of Khe Ro requires more than 90 years. With these rates in mind, forest management plans should be made for each forest stand, due to different tree growth relationships.

4.8.2.2 Estimate of height growth

There are two ways to estimate annual height increment: either based on the relationship between age and height or dbh and height (SCHÖNGART 2003). In the present work, for the trees where ring analysis was a possibility (40 trees in Tuan Dao and 30 trees in Khe Ro) the regression analysis shows that there is no significant correlation between height and age; regression coefficients were 0.14 and 0.20 in Tuan Dao and Khe Ro, respectively. However, the relationship between dbh and height was proven, and the height growth models, which were tested in 4.5.1 (also see tab. 4.19), enable the prediction of height growth based on dbh.

Table 4.30 The models for estimating height growth of different species in Tuan Dao and Khe Ro, NE Vietnam.

Species	Height growth models
Tuan Dao	
Mischocarpus oppositifolius	$h = e^{0.2204296 + 1.983212 \cdot \ln d - 0.394684 \cdot (\ln d)^2}$
Pygeum arboreum	$h = 2.803224 + 0.4510967 \cdot d - 0.0046727 \cdot d^2$
Erythrophloeum fordii	$h = 1.3 + 0.7943293 \cdot d - 0.0141215 \cdot d^2$
Lithocarpus ducampii	$h = 4.7983374 + 0.1849815 \cdot d + 0.0012966 \cdot d^2$
Khe Ro	
Erythrophloeum fordii	$h = 6.3972174 + 0.269801 \cdot d + 0.0007341 \cdot d^2$
Castanopsis indica	$h = e^{0.2966555 + 2.142208 \cdot \ln d - 0.0287704 \cdot d}$
Pygeum arboreum	$h = e^{1.4426415 + 0.2437206 \cdot \ln d + 0.0399511 \cdot d}$

Based on the relatively high correlation (see table 4.19), the models presented in table 4.30 are applied to calculate the height increments for every individual tree and species. These results are used to estimate mean and current annual increment of volume (MAI and CAI).

4.8.2.3 Estimate of volume growth

Volume and volume growth of an individual tree are the most important parameters of a stand. This information enables the forester to predict the stand yield and thereby effectively management the forest (MISCHERLICH 1978). Early in life, the height growth of the tree is the most important factor, but as maturity approaches, the volume increment is mostly due to changes in diameter (FREDERICK 1950). After Van LAAR and AKCA (1997), the volume of an individual standing tree is a function of the basal areas, tree height, and form factor, where the tree heights were predicted based on the relationship between dbh and height, as referred to in 4.8.2.2.

ASSMANN (1970) indicated that the progress of the volume increment can be used to define the natural age phases, particularly if it is essential to decide to harvest an individual tree at the time when it has reached its highest mean volume. This determination is made using the mean annual increment of volume (MAI) and current annual increment of volume. MAI is the average annual growth in volume for a certain period, whereas the CAI describes the actual annual increment for a certain year. The harvest age is the age where the two curves intersect. . For every species in the study sites, the MAI and CAI were calculated and fitted by exponential equation as shown in figure 4.17 and figure 4.18.

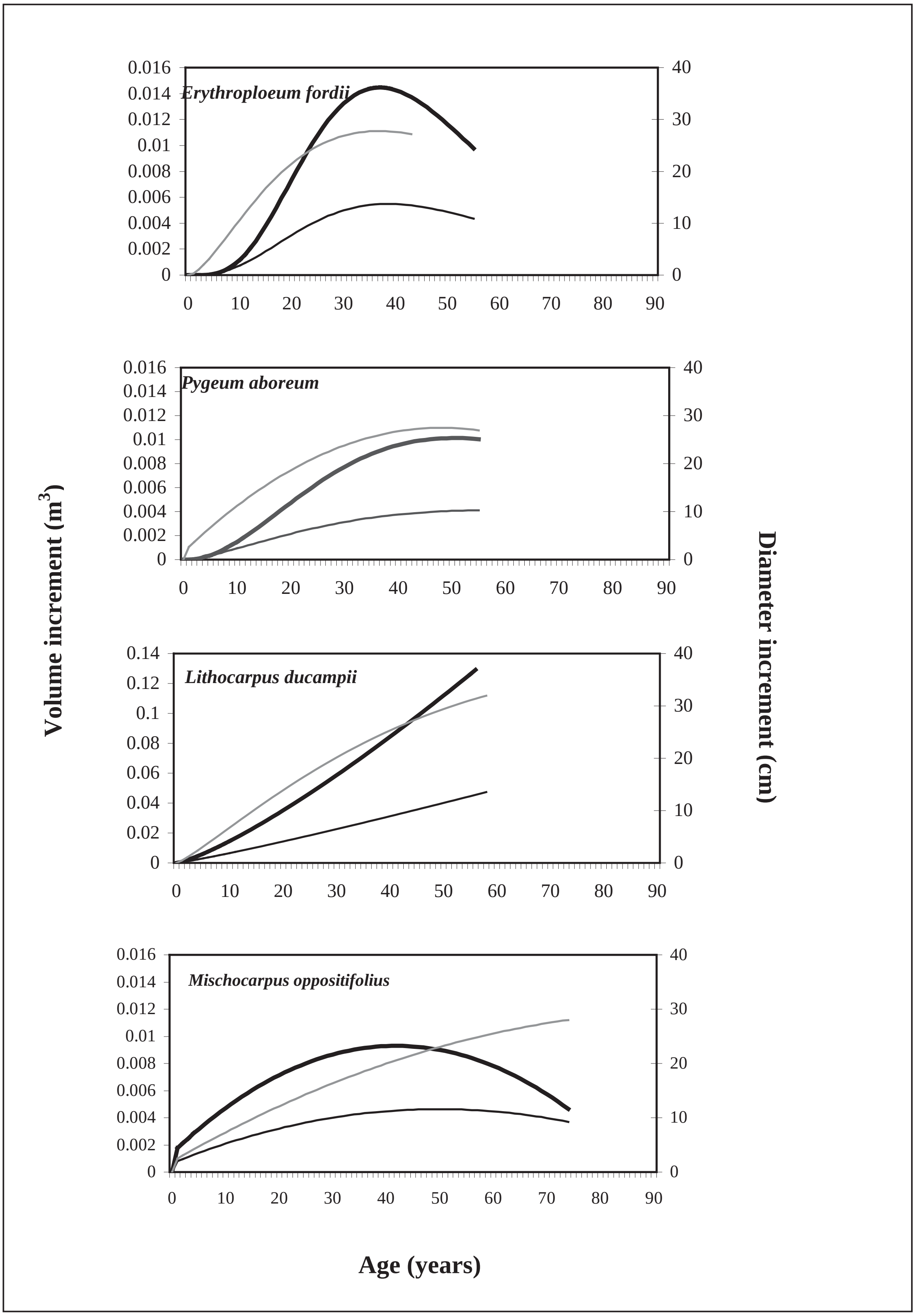

Fig. 4.17 Fitted curves of current annual and mean annual increment in volume and dbh increment of four tree species of Tuan Dao. Diameter increment (grey), MAI (black), CAI (black bold)

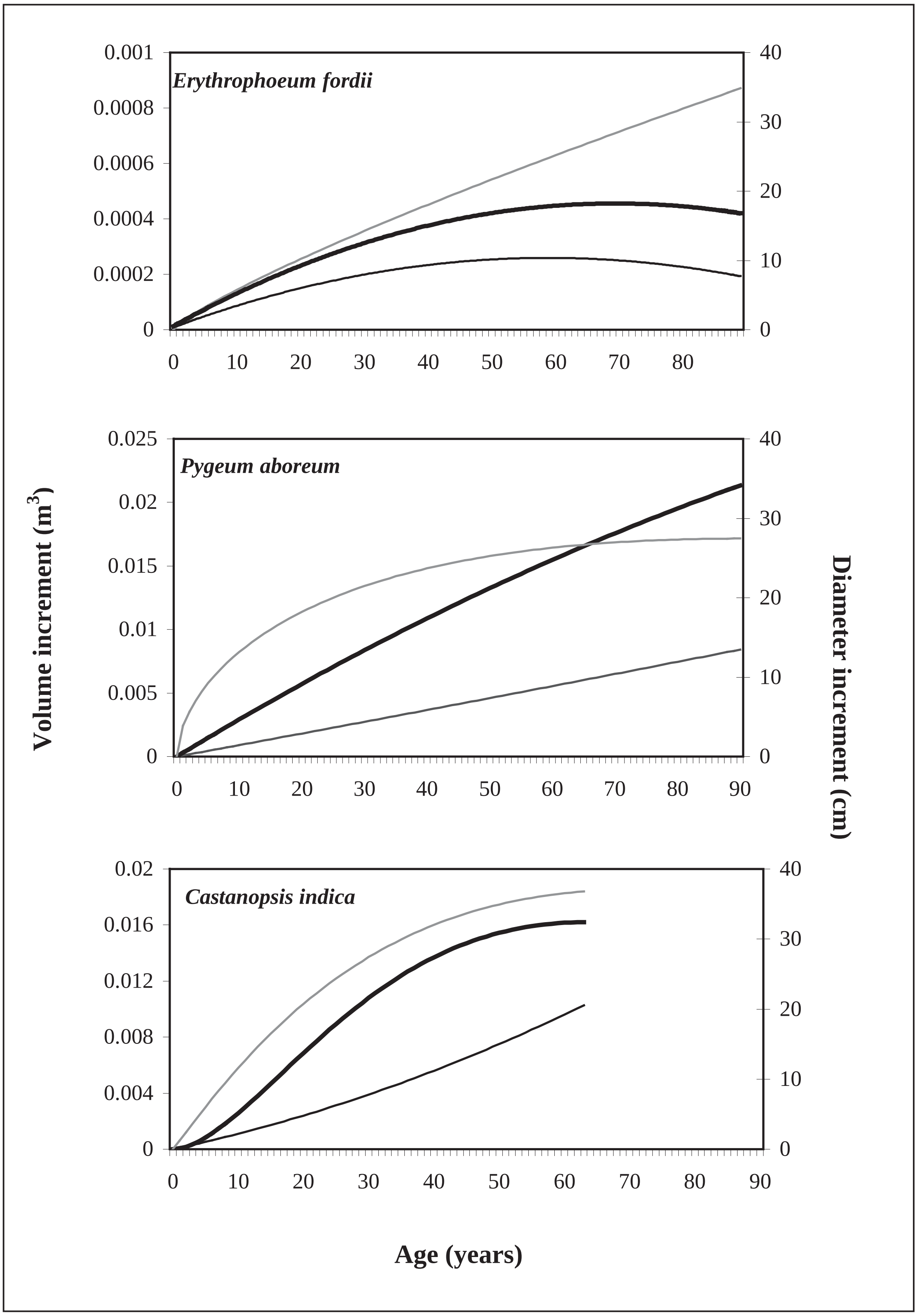

Fig. 4.18 Fitted curves of current annual and mean annual increment of volume, and diameter increment of three species of Khe Ro. Diameter increment (grey), MAI (black), CAI (black bold)

The three curves above (MAI, CAI and dbh increment) in the figures 4.17 and 4.18 are used to estimate the optimum rotations for the researched tree species and adjust the MHD accordingly, especially for the production forest of Tuan Dao. For Khe Ro, because of its protection function, the MHD is only considered as a reference for developing sustainable management strategies based the long-term growth patterns of the forest species.

In different forest types, forest successions, and species, trees culminate at different ages. A wide range of MHD and corresponding cutting cycles have been already suggested for different tropical forest regions. SCHÖNGART (2003) recommended a MHD between 47-58 cm and rotations of 30-78 years for soft wood species in inundation forest in Central Amazonia, and a MHD between 53-70 cm and a rotation of 115-196 years for hard wood species in this area. The rotations and MHD of teak trees in two natural forest areas of Myanmar were adjusted to 147 years and 70 cm based on the culmination points of the volume increment curves (MAI and CAI) (KYAW 2003). Although in the cases of *Erythroploeum fordii* and *Mischocarpus oppositilius* of Tuan Dao CAI are at culmination, in the context of current study results, the MAI and CAI curves of all species have not cut yet. The recommendation of the appropriate rotations and MHD are therefore not reliable. Extrapolation was not used for the study, because of the distribution cloud of obtained data. Due to the lack of data for older trees, extrapolation would not have been accurate (KLEINN 2005). Based on volume increment, the given legal MHD of 35 cm for these researched species are lower than the possibly true MHD (see fig. 4.17, 4.18). For the polycyclic management system, in which the number and quality of remaining trees are regarded, further research is needed to combine these important factors and introduce the proper MHD and rotation.

4.9 Tree and osmotic potential relation

Water is commonly the most limiting factor for plant growth under natural conditions, particularly in areas where seasonal temperature changes are not limiting to plant growth. Water stress may occurs during those periods when water uptake does not cover the water losses of the plant (MEDINA 1989). To cope with this water stress, tree species have various mechanisms, whereby osmotic adaptation in plays a crucial role. Starting already in the early 20th century, thousands of measurements were made of the osmotic potential of plant tissue as an indicator of plant water stress (KRAMER and BOYER, 1995). ZHANG et. al. (1999) has pointed out that plants have are always coping with water stress and experience constant fluctuations in the availability of water. They evolved adaptive features to search for and absorb water through their root systems, based on their capacity to adjust osmotically. So called osmotic adjustment, defined as a lowering of osmotic potential due to the net accumulation of solutes in response to water deficits, has been considered to be a beneficial drought tolerance mechanism in some species (GIRMA and KRIEG 1991). Based on research in tropical regions of Southern Africa and America, MITLÖHNER (1997a) indicated that it is possible to quantify the current water and salt regime of the soil and the plant itself by measuring the internal potentials of plants. The osmotic potential can be considered a measure of the osmotic adaptability of trees under the less favorable “salt” condition of the site. Regarded as a basic condition for osmotic water transport, the osmotic potential within the plant must be at least equal to the concentration of soil solution (MITLÖHNER et al. 1997a). It has been tested and proven through numerous studies carried out in different tropical regions, in SE Asia (MITLÖHNER et al. 1997, FU 2001, SIVANANTHAWERL 2001, KYAW 2003), in Africa (MITLÖHNER 1997, GEBREHIWOT 2003, KRUG 2004), and South America (MITLÖHNER 1990, 1997, 1998)

MITLÖHNER (1998) stated that it is possible to identify the requirement of a species in a particular site by measuring their internal potentials. These results can then be used to determine the appropriate tree species for a certain site. In the present riparian forest areas, in which changes in species composition are likely due to changes in both salinity and hydro-period, the plant internal osmotic potential should be investigated in order to find out how far the tree species actually adapt to their sites and how the riparian condition affects the osmotic potential of the trees on the site. Therefore, *Erythrophloeum fordii*, *Pygeum arboreum*, *Lithocarpus ducampii*, *Vatica tonkinensis*,and *Madhuca pasquieri* at Tuan Dao and *Erythrophloeum fordii*, *Pygeum arboreum*, *Canarium album*, *Castanopsis indica*, and *Pithecellobium clypearia* at Khe Ro site, which are either dominant in the areas or commercially important, were chosen for measurement. Two samples of *Aquilaria crassna*, a rare and precious species, which still exists at the Khe Ro site, were also taken.

The osmotic potential of leaves generally varies throughout the day. The transpiration from leaves and canopies is clearly under both physical and physiological control. Apart from internal characteristics of plant cells, the variation of the osmotic potential depends on changes in microclimate condition (Temperature, light, interalia...) (PFEFFER 1877). However, as result of the night re-saturation process, it attains its peak at predawn and reaches its minimum at midday due to the loss of water from the leaves (GEBREHIWOT 2003, FU 2001). Based on this hypothesis, the osmotic potentials of chosen species were measured in MPa as described in 3.2.3. The standardized osmotic potential was determined in order to indicate the long-term osmotic constitution of the soil at the given site (also see 3.2.3). All results are summarized in table 4.31.

Table 4.31 Negative plant osmotic potentials (mean ± Sx) and standardized negative osmotic potential of studied species of Tuan Dao and Khe Ro in rainy season 2002 (N= 6 for each species per site, except *Aquilaria crassna* (N= 2).

Species	Tree leaf osmotic potential (MPa)		
	Midday	Predawn	Standardized
Tuan Dao			
Erythrophloeum fordii	-0.21 ± 0.04	-0.19 ± 0.03	-0.16
Pygeum arboreum	-0.18 ± 0.03	-0.14 ± 0.03	-0.14
Lithocarpus ducampii	-0.20 ± 0.06	-0.22 ± 0.06	-0.17
Madhuca pasquieri	-0.23 ± 0.02	-0.25 ± 0.04	-0.23
Vatica tonkinensis	-0.21 ± 0.03	-0.19 ± 0.02	-0.15
Khe Ro			
Aquilaria crassna	-0.47 ± 0.19	-0.32 ± 0.06	-0.31
Erythrophloeum fordii	-0.32 ± 0.08	-0.34 ± 0.06	-0.25
Canarium album	-0.22 ± 0.04	-0.23 ± 0.04	-0.17
Castanopsis indica	-0.26 ± 0.07	-0.26 ± 0.05	-0.17
Pithecellobium clypearia	-0.42 ± 0.70	-0.40 ± 0.12	-0.28
Vatica tonkinensis	-0.32 ± 0.05	-0.33 ± 0.11	-0.30

According to table 4.31, the midday and pre-dawn values are very close to each other. The osmotic potentials are all much less negative than the osmotic potentials which have been recorded in different tropical regions, especially in the tropical dry areas. While the low value may be considered a limiting factor in the dry areas, in the context of the actual site these high values can possibly indicate the favorable water condition of the site for tree growth, especially in Khe Ro. MITLÖHNER (1997a) argues that in the evergreen moist forest areas, a particularly high osmotic potential in the tree species is a great advantage. The actual values range from -0.14 to -0.23 MPa in Tuan Dao and from -0.17 to -0.31 MPa in Khe Ro. There were overall significant difference found between the tree osmotic potentials in Tuan Dao and Khe Ro (midday, pre-dawn, standardized), trees of Khe Ro had higher values than those of Tuan Dao (ANOVA, $p<0.05$).

Furthermore, midday and predawn osmotic potentials are significantly variable among tree species on both sites (ANOVA, $p<0.05$, paired t-test).

It is known that differences in osmotic potential may help explain the relative distribution of species along environmental and successional gradients (GEBREHIWOT 2003). For the present study, the differences between predawn and midday osmotic potentials range from -0.05 to 0.10 MPa in Tuan Dao and from -0.27 to 0.23 MPa in Khe Ro. The actual finding shows that not all tree species have more negative mean midday osmotic potentials than mean predawn osmotic potentials. This was the case for *Lithocarpus ducampii* ,and *Madhuca pasquieri* of Tuan Dao and *Erythrophloeum fordii*, *Canarium album* and *Vatica tonkinensis* of Khe Ro (see table 4.31). This means that the relaxation osmotic potential value at night of many individual trees (predawn values) is more negative or equal ($\geq$) to their osmotic potentials at noon (midday values). Similar results were also found by *Shorea roxburgghii* and *Hopea odorata* of evergreen moist forest and *Vitex pubenscens* and *Sondora cochinchinensis* of dry deciduous forest of Binh Chau, Vietnam (MITLÖHNER et al. 1997), as well as in some observations of *Eucalyptus grandis* of Sri Lanka (SIVANANTHAWERL 2001).

GRAHLE (1934) found that the course of osmotic values over a year was very variable. Maximum and minimum osmotic values were not always at the same time of day and absolute highs and variation intervals changed with the season. In the summer months, the daily curves were regular, while they were often irregular during winter and early year. Thus, in the future, investigations focusing on the diurnal trends in osmotic potential inside such closed evergreen riparian forest condition are required in order to develop the optimum timetable for the future measurements of plant osmotic potential for these areas.

The mean values and standard deviations of osmotic potentials both in midday and pre-dawn (mean $\pm S_x$) as well as standardized values, which can be considered to be an indication of tree adaptation to the site condition of the study sites, are represented in figure 4.19.

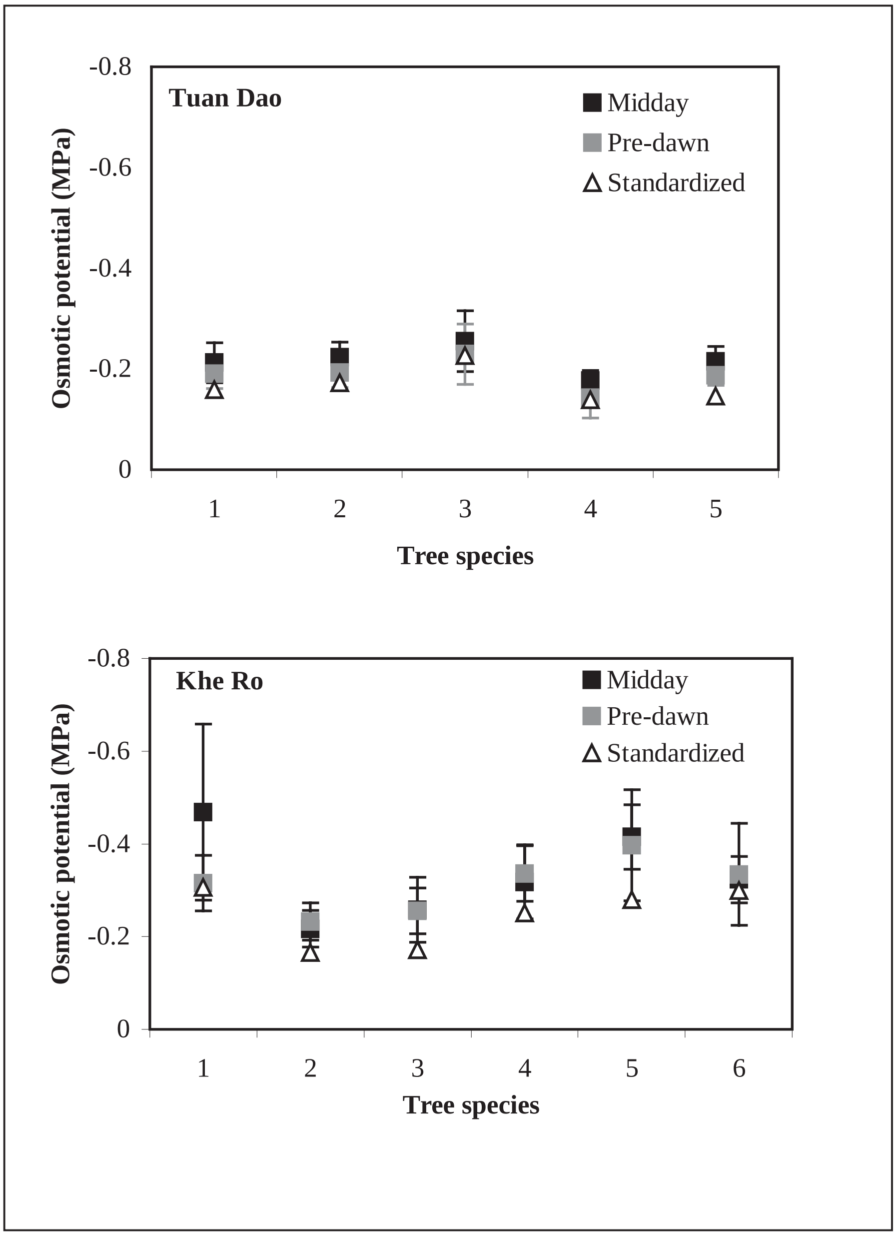

Fig. 4.19 Osmotic potential: midday, pre-dawn (mean ± S_x) and standardized of five tree species of Tuan Dao (1: *Erythrophloeum fordii*, 2: *Lithocarpus ducampii*, 3: *Madhuca pasquieri*, 4: *Pygeum arboreum*, 5: *Vatica tonkinensis*) and 6 species of Khe Ro (1: *Aquilaria crassna*, 2: *Canarium album*, 3: *Castanopsis indica*, 4: *Erythrophloeum fordii*, 5: *Pithecellobium clypearia*, 6: *Vatica tonkinensis*).

As can be seen in figure 4.19, the standard deviations of all tree species are low and similar in Tuan Dao, which indicates the homogeneous condition of this site in the rainy season (MITLÖHNER 1998). However, there is much higher variation at the Khe Ro site, especially by *Aquilaria crassna*. *Madhuca pasquieri* of Tuan Dao and *Aquilaria crassna* of Khe Ro have the lowest osmotic potentials, which highlights their drought resistance as compared to the other species (also see table 4.31). In brief, all research tree species show their adaptation to the regular wet condition of the study sites by lowering the salt concentration. Hence, the variation of osmotic potentials between two sites and among species may present the osmotic adjustment of tree species to adapt to a particular site.

For arid zone forestry in Namibia, KRUG (2004) noted that within riverbeds, the trees closer to the water had more moderate soil water available than trees further away. In this study, answering the question of how the tree species adjust to different osmotic potentials along gradients from the riverbank to forest edge is important in terms of interpreting the influence of irregular flooding of vegetation community here. Fig. 4.20 illustrates the relationship between tree position and osmotic potential values as well as with soil osmotic values.

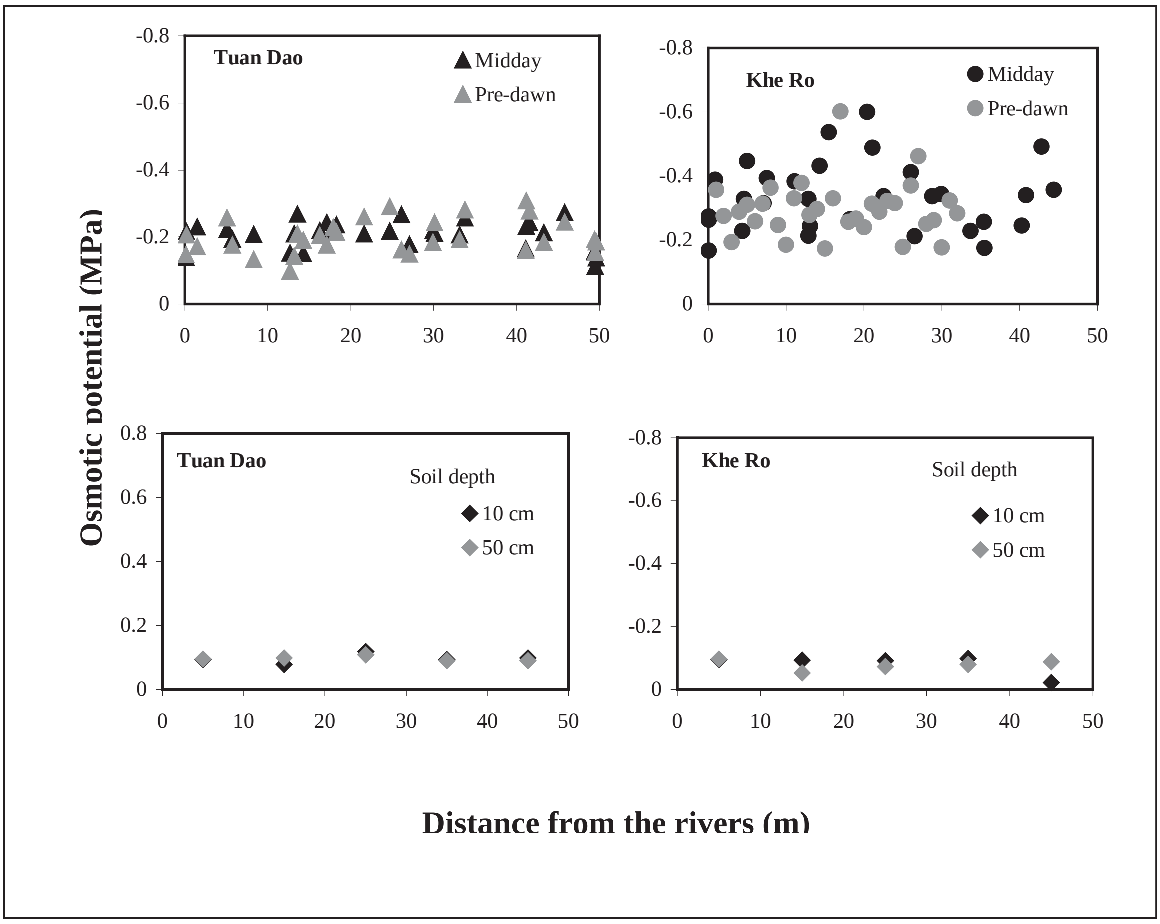

Fig. 4.20 The changes in osmotic values at different distances from the river in the study areas. Osmotic potential of trees (upper), and osmotic values of soil (down).

The osmotic potentials were much more scattered in Khe Ro than in Tuan Dao. Additionally, it can be seen that osmotic values of soil solution are distinctively less negative than those of trees. According to the figure 4.19, the osmotic potential of trees adjacent to the river bank seem to be lower than those at locations further away (with a measuring error of cryoscopy of ± 0.2 MPa). The regression analysis, however, shows no distinctive signal of the position influences on osmotic status of trees at the both study sites. The irregular flooding conditions of these riparian forest areas may not have a considerable impact on the osmotic situation of trees and soil.

5. Conclusions and recommendations

5.1 Current status of the research stands

Adjacent to rivers or streams, riparian forests provide essential life functions in the transitional zones between terrestrial and aquatic ecosystems (ANONYMOUS 2002). In NE Vietnam, even though they occupy only a small proportion of most watersheds, riparian forest areas perform important hydrologic, geomorphic, and biological functions. Despite their functions, they have been degraded and fragmented because of the multiple uses by local people, such as the extraction of timber and non-timber products or use of the land for agriculture. In recent years riparian forests have begun to receive legal recognition as places requiring special attention. A notable effort has been made, mainly focused on protecting and conserving some riparian areas or aspects of riparian areas. Successful restoration, however, requires local knowledge of hydrology and ecology including the range of natural variability, disturbance regimes, soils, landforms, and vegetation.

The typical high species richness of tropical forests was found in the present study: the number of tree species per hectare in Tuan Dao is 92 species and Khe Ro is 118 species (trees ≥ 5 cm dbh). The diversity indices in both study stands were found to be very high (see chapter 4.4.3). In addition, frequency diagrams show high degrees of floristic heterogeneity, in which high values in classes I and II and low values in IV and V are predominant (LAMPRECHT 1989). The zonal differences show no clear effect on the species diversity. Concerning the similarity of the researched stands, the species found in Tuan Dao are distinctly different than those found in Khe Ro (Ks = 46.7%). However,, the similarity coefficient (Kd), which is based on species dominance (basal area per species), showed a much higher similarity value by (71.6 %). In those riparian areas, species composition is not influenced distinctively by different riparian zones (see chapter 4.4.4).

Here, the notable influence of the hydrologic conditions was represented by very acidic soil with high pH_{kcl} and Al^{+++} content. In terms of the riparian vegetation communities, a lower number of under-storey species was found near to the river than far from the river. It is in agreement with the statement that species numbers in the understorey of the forested wetland dropped sharply in the wettest portions of floodplain (LUGO et al. 1990). Further characteristics of the present riparian forest areas include the high abundance of bamboos (*Lingnania chungii* and *Noehouzeaua dulloa* of Tuan Dao, *Noehouzeaua dulloa* and *Bambusa sp*. of Khe Ro), *Macaranga denticulate*, lianas, and grasses.

Khe Ro has higher total basal area and mean diameter than Tuan Dao. Significant difference of these parameters between zone I and II were, however, not found (see 4.5.2). In all zones and sites, number of trees decreased with greater diameter classes. Inverse J-shape functions gave the best fit for diameter distribution of both areas. The Parabola function, proposed by PRODAN (1965), was found the best fitting for the height curves of different sites and zones. However, there were different trends and height curve models among species due to different tree-growth relationships; for instance, between fast growing tree species and slow growing tree species.

Following LAMPRECHT (1989), with regard to the vertical structure, species that showed a regular vertical distribution (were represented in all storeys) constitute 40 - 48 % of total species number in both sites, Although there is high abundance of regeneration, juveniles, and saplings, the quality of regeneration of woody species seems to be limited. Regeneration of the pioneer species and light-demanding fast growers, eg. *Cratoxylum pruniflorum, Phyllanthus reticulata, Canarium album,* and *Garcinia oblongifolia* in Tuan Dao and *Maesa balansae, Daphniphyllum calicinum, Aporusa dioica,* and *Garcinia oblongifolia* in Khe Ro, are dominant, mostly in individuals as saplings. Many of the commercial timber species, like *Vatica tonkinensis, Erythrophloeum fordii, Madhuca pasquieri Mischocarpus oppositifolius, Lithocarpus ducampii,* and *Castanopsis indica* etc. performed in the group of 15 most abundant species at the both sites. Their representation is in fact more or less restricted to the juvenile class.

Tree species of both study sites showed a positive relationship with the annual rainfall and total precipitation in the rainy period (see chapter 4.8.1). Tree species react differently to the site conditions, which is demonstrated in tree growth relations. Tree species of Tuan Dao showed higher mean annual diameter increment than those from Khe Ro. Trees reached the legal MHD with a wide range of ages. Nevertheless, because of the age limitation of researched tree species, it was not possible to recommend a reasonable rotation and to adjust MHD for them.

Significant differences in osmotic potentials were found between the two sites and among species at each site. The osmotic potentials measured in both study areas are distinctly higher compared to research results that have been documented from different tropical regions. In contrast to tropical dry areas, these less negative osmotic potential values of tree species can be considered as adaptation characteristics due to the periodic flood conditions. The variations of plant osmotic potential between the two study sites and among the species in a site indicate the wide range of osmotic adjustment of the tree species in adapting to the actual site conditions. It would be beneficial to deepen the research in this topic for riparian moist evergreen forest areas.

5.2.1 Recommendations towards sustainable management strategies for riparian forests, NE Vietnam

Only during the last decade have riparian forests begun to receive special attention. This attention has focused on protection and preservation of riparian forest through the creation of restricted areas. Few efforts, however, reflect awareness of riparian forest areas as unique physical and natural systems and consider the local knowledge of hydrology and ecology, including the range of natural variability, disturbance regimes, soils, land-use forms, and vegetation. Developing sustainable management strategies for this area requires a combination of passive and active approaches. The protection of riparian vegetation from future harvest would be a passive approach. Active restoration approaches should emphasize people-based approaches, including buffer development, planting native trees, and encouraging more participation of local people in management activities. Figure 5 presents the general strategies for sustainable riparian development.

In the protection forest of Khe Ro, where all forest interventions are forbidden, the approaches mainly focus on the development of a buffer zone. The integrating of environment awareness education of for the local people and programs focusing on improving the standard of living are really needed, in order to reduce the dependence on forest products.

In the production forest of Tuan Dao, the silvicultural practices of rehabilitation activities based on actual research have resulted in activities such as enrichment planting of native and economically valuable tree species such as *Erythroploeum fordii, Vatica tonkinensis,* and *Madhuca pasquieri,* as well as multi-purposes, fast growth species such as *Canarium album, Mischocarpus oppositifolius Lithocarpus ducampii,* and *Castanopsis indica*, which have demonstrated their adaptation capacity in the areas of the present research. Promoting natural regeneration by cutting climbers and lianas, eliminating undesirable tree species or bamboos, as well as liberating valuable mother trees are necessary in order to improve the quality of the forest composition and protection function of the forest areas, as well as to ensure the sustainable development of the stand.

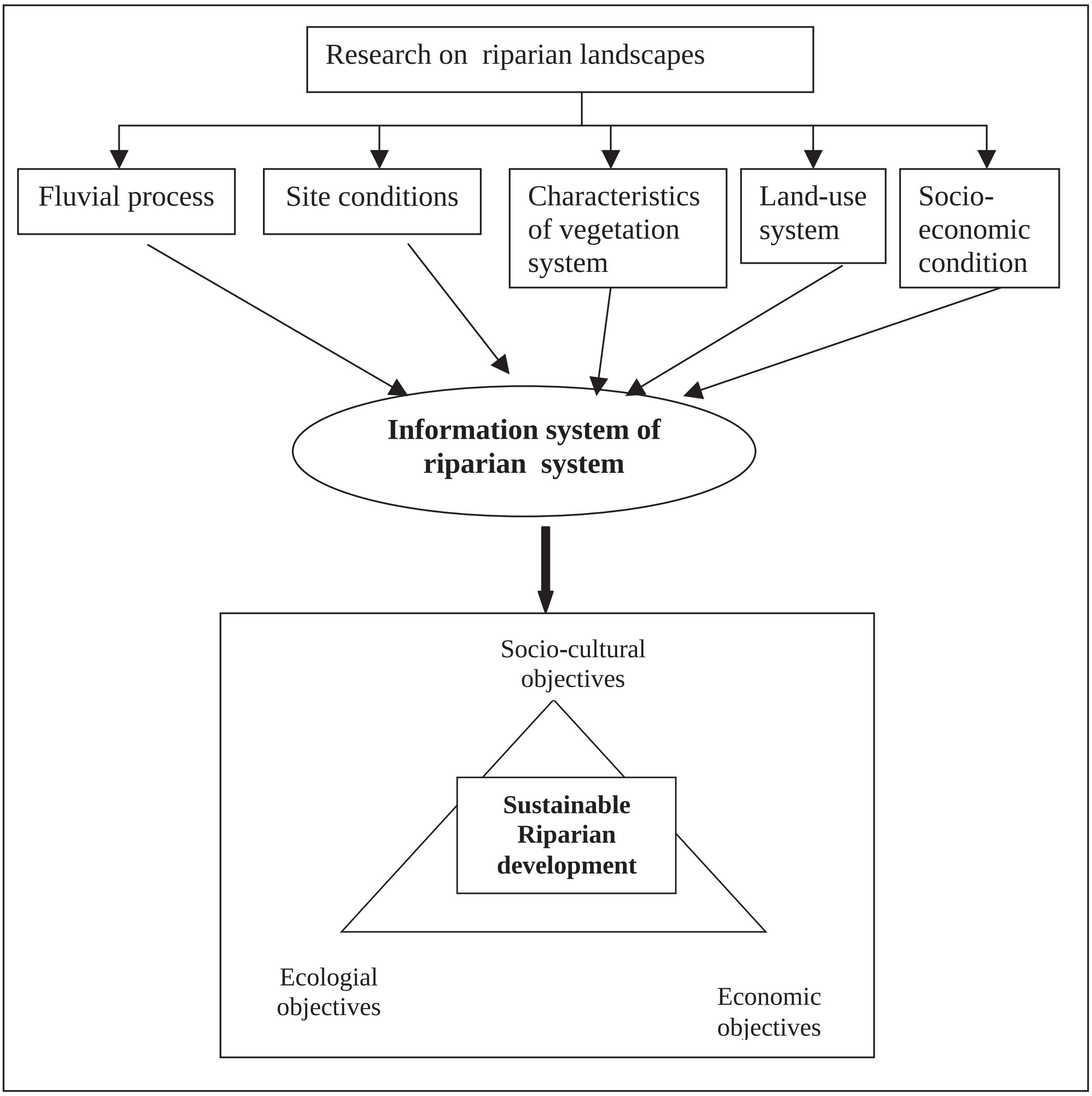

Fig. 5 Research strategies for sustainable riparian area development

Future research of riparian areas should extend the investigation to include varying site conditions and additional tree species (beyond traditionally harvested economic species), in order to obtain information on the growth behaviour of these endangered and important ecosystems. This information can then be used to apply future silvicultural approaches to sustainably manage riparian areas. A better understanding of the complex interactions in these landscapes could be helpful in developing sustainable management operations in order to reserve these endangered ecosystems.

The following research gaps are recognized from this study:

- In order to reduce the burden on forest due to uncontrolled forest utilization from local people, their economic situation should be improved through social forestry development. For this purpose, the development of new technology in agriculture and forestry based on ideas of local people should be implemented.

- More silvicultural trials of enrichment planting of different tree species and techniques should be carried out that include the participation in implementation of local people. Furthermore, the necessary approaches should be applied so as to improve the protection function of this special forest formation, even in the strict protection zones.

- The overall riparian forest areas of NE Vietnam need to be mapped, documented and investigated using GIS (Geological Information Systems). In addition, the riparian forests should be classified for these areas based on geomorgraphy, hydro-period, and river process (alluvial process). This would serve as an effective tool for developing management strategies appropriate for the individual areas.

- The relationship between flooding and tree growth is still not well known in the whole riparian landscape, as evidenced by contradictory results found in the literature. Dendrochronology is a useful tool to study the temporal pattern of trees. Tree rings have been used to reconstruct past hydrologic conditions (JEAN and BOUCHARD 1996). The present study pointed out a possibility for dendrochronogical research in this domain of science.

6. Summary

In NE Vietnam, especially in the context of uneven topographical characteristics, the riparian forests are well known for their role in controlling water sources, water runoff, flood, drainage, and navigation improvement for the basin regions and stream bank erosion. In spite of the important ecological role, natural riparian forests in NE Vietnam have been subject to human disturbances. They are continuously degraded by anthropogenic activities in which tree harvesting and exploiting are prominent. These interventions have resulted in fragmented, degraded, and narrow riparian forest strips. The number of valuable tree species has been reduced drastically. Consequently, along most of big rivers in the NE, riparian forests do not exist any more. The remaining forests now occur along Branch Rivers or streams as overexploited forests or bamboo mixed forests.

The restoration of these forests demands an understanding of linkages between processes, the former and past management history of the vegetation communities, and the riparian vegetation and river process in the context of the site conditions. The research complied information about vegetation composition and the structure and dynamics of the riparian forests as well as the plant responses to the specific site conditions in two riparian forest areas in NE Vietnam. In order to fulfil the research objectives, two riparian forest stands in Tuan Dao and Khe Ro, NE Vietnam were choosen in the present work.

The study methodology was divided into five major parts: 1) stand structural analysis, 2) natural regeneration, 3) tree ring analysis, 4) plant water relationships, and 5) social method. With special characteristics of geology and topography, the inventory was conducted on 40 transects (10 m x 50 m) along two rivers to obtain dendrological composition and stand structure. The transects were systematically located perpendicular to the direction of the riparian forest every 150 m. For structure analysis, all the trees in a transect with dbh $\geq$ 5 cm were recorded. The tree positions were noted based on the distance from centreline. For natural regeneration investigation, subplot (5 m x 5 m) were placed on the left side of transects. In these subplots, all the trees with

dbhs ≤ 5 cm were registered in two height classes: juveniles were trees ≤ 30 cm height. Saplings were trees between 31 cm and 130 cm and dbh < 5 cm.

With regard to the changes between values at different gradients away from the river bank, species composition, structure, and dynamics were analyzed in different zones (Zone I: 1-25 m from the river, influenced strongly and more regularly by flooding; zone II: 25-50 m from the river, where flooding was not an influence) as well as in different distances classes of 1-5, 10-15, 20-25, 30-35, 40-45 m from the river, where the compartment B sample subplots were placed.

For tree ring analysis, five dominant tree species that possibly show distinct annual rings were selected. A total of 70 sample trees (40 from Tuan Dao and 30 from Khe Ro) which had cylindrical straight boles and no visible damage were cored at the height of 1.3 m with increment borers and analysed using standard dendrochronology methods in Göttingen.

For osmotic potential investigation, five dominant and commercially important species from Tuan Dao and six species from Khe Ro were selected. Six leaf samples per species were taken at Midday and Predawn. These leaf samples were weighed in the fresh state under field conditions using a portable balance with a precision to 0.01 g. After killing-off in order to avoid enzymatic changes, the samples were packaged in the dry state for transportation. The dry samples were carried to Göttingen to measure the freezing point using a cryoscopic method.

In order to get an overview of the areas and describe and understand the utilization and development history of the study sites, some tools of RRA (Rapid Rural Appraisal) and PRA (Participatory Appraisal) including secondary data-reviews, direct and participant observation, Semi-structured interviews, and Ranking techniques were used.

The main results obtained from this study as follow:

- Resulting from the past utilization and management history, the study forest areas are degraded. Although legal forest utilization is more or less forbidden due to the function of watershed protection of these forests, the forests are continuously illegally used for timber, bamboos, fuel wood, and NTFPs. Protecting these forests while including communities is getting more and more recognition and requires socio-economic development in the buffer zones (chapter 4.1).

- In the present study, the systematic transect sample design (10x50 m) along the river was suitable for investigating the specific conditions of the narrow riparian forest strips. The position of all trees ≥ 5 cm dbh were marked based on their distance from the riverbank in the inventory, which can help to evaluate the changes in vegetation composition along different distances from the river.

- The sample size has been reached in according to the requirements of the species-area curves and standard error. In a sample area of one hectare, a large number of tree species (trees with dbh ≥ 5 cm) are found in the study. 788 trees belonging to 92 species of 44 families were found in Tuan Dao. This number was significantly higher in Khe Ro, where 983 stems belonging to 118 species of 49 families were found. In spite of high number of tree species, many are present in very low abundances and densities.

- Diversity indices are high in both areas. SIMPSON indices range from 0.96 to 0.97 and SHANNON-WIENER indices vary from 3.70 to 3.89. However, species diversity along the riparian gradient did not show significant variation. The similarity index (K_d), which is based on basal areas, gives higher similarity values (71.6 %). However, in terms of floristic composition, only 49 common species were found in the two stands (K_s is by 46.7 %) (chapter 4.2).

- Both areas are dominated by aggressive, fast-growing light-demanding species like *Macaranga denticulate, Wrightia tomentosa,* and *Eurya nitida* (in Tuan Dao) and *Engelhardta chrysolepis, Maesa balansae,* and *Aporusa dioica* (in Khe Ro). Higher number of bamboos characterized the zones adjacent to the river of the riparian forest. Nevertheless, there is no clear difference in species diversity and composition between the two gradient zones away from the river bank

- The quadratic mean diameter (d_q) and total basal area of Khe Ro are significantly higher than those of Tuan Dao. Moreover, trees of zone I have comparatively higher mean quadratic mean diameters as well as total basal areas than those of zone II. The stem diameter size distribution follows the inverse J-shape curve, which is typical in natural forest regenerating from seed. The same distribution patterns are found in all zones of two riparian forest areas. This decreasing shape indicates the climax stage of the current study areas (chapter 4.4.2).

- In the diameter-height relation, PRODAN´s model was found to be best fitted for both stands and all zones. The Khe Ro stand shows a superior diameter-height growth relationship than the Tuan Dao stand. The higher degree of scattering of the point cloud indicates the lower homogeneous of Tuan Dao stand. Different species in different study areas were fitted best with different models (chapter 4.5.1).

- In Khe Ro, the LOREY´s mean height is 13.1 m. Top height ranges from 13.8m (h_0) to 15 m ($\overline{h}_{100}$**).** Tuan Dao forest has significant lower mean height as well as top height than Khe Ro forest: h_L = 9.5 m, h_0 = 10.8 m and $\overline{h}_{100}$ = 11.1 m. 40% of the tree species in Tuan Dao and 48 % of thetree species in Khe Ro were classified as regular vertical distribution species, which show up in all stories. 30% of Tuan Dao species and 35 % of Khe Ro species are limited to the lower strata. This indicates an adequate amount of regeneration but poor regeneration by the potential crop tree species in the study areas (chapter 4.5.2, 4.5.3).

- For assessment of stand productivities, the stand volume, which was estimated for all the recorded trees with dbh ≥ 5 cm, of Tuan Dao is 76.5 m^3/ha, significant lower than that of Khe Ro (147.7 m^3/ha). Correspondingly, the Khe Ro stand has a higher volume proportion of potentially valuable tree species. Moreover, the above ground biomass of trees with dbh ≥ 5 cm at the Khe Ro site is obviously higher than that at Tuan Dao site.

- In the natural regeneration, the number of juveniles is markedly higher in the Khe Ro stand, but there was no statistically significant difference in the density of saplings. Regeneration of the pioneer species and light-demanding fast growers, eg. *Cratoxylum pruniflorum, Phyllanthus reticulata, Canarium album,* and *Garcinia oblongifolia* in Tuan Dao and *Maesa balansae, Daphniphyllum calicinum, Aporusa dioica,* and *Garcinia oblongifolia* in Khe Ro are dominant. Regeneration of many of the commercial timber species like *Vatica tonkinensis, Erythrophloeum fordii, Madhuca pasquieri Mischocarpus oppositifolius Lithocarpus ducampii,* and *Castanopsis indica* are found, but they are more or less restricted to the juveniles class. The abundance of juveniles and saplings shows a slight difference along different riparian strips; however, there is no statistically significant change in their number at different distances from the river (chapter 4.7).

- Tree ring analysis shows that the investigated species of both study sites are positively related to the amount of annual rainfall and total precipitation in the rainy period. Tree species in Tuan Dao showed higher mean annual diameter increment than those from Khe Ro. Based on the volume increment, the rotation age and harvestable dbh limit of investigated tree species could be adjusted. As a consequence of the young state of the investigated stands, the data sources were not adequate for identifying the appropriate parameters, and an extrapolation can lead to high estimating error. Further investigation is recommended in the study areas.

- In the investigation of internal osmotic potential, all OP values are particularly less negative than the results which have been recorded in different tropical regions. This is especially true for results from tropical dry areas, where the tree species adapt to the site condition with absolute negative OP values. The present OP values range from -0.14 to -0.23 MPa in Tuan Dao and -0.17 to -0.31 MPa in Khe Ro. These particularly high OPs could possibly indicate the favorable availability of water for tree growth. Osmotic potentials varied distinctively between the two study sites and among tree species. However, this was not found to be a distinctive signal of the position influences on osmotic status of trees at the study sites (see chapter 4.9).

In conclusion, it is recommended to develop sustainable management strategies for riparian areas. This requires a combination of passive and active approaches. Active restoration approaches should emphasize people-based approaches, including buffer development, planting of native trees, and encouragment more participation of local people in management activities. In buffer zone development, the silvicultural practices in rehabilitation activities based on actual research result of vegetation composition, structure and dynamics such as enrichment planting with native tree species, medicinal plants or promoting natural regeneration are requisite in order to improve quality of forest composition and protection function of the forest areas. With regard to historically harvested riparian forests, future research should extend the investigation to additional tree species and varying site conditions on further riparian forests to achieve information on growth behaviour of these endangered and important ecosystems on sustainable management and future silvicultural approaches.

7. Zusammenfassung

Im Zusammenhang mit den topographischen Besonderheiten NO Vietnams haben die flußbegleitenden Wälder eine wichtige Funktion hinsichtlich Wasserabfluß, Hochwasserschutz und Erosionsverhinderung. Trotz dieser besonderen Bedeutung sind die Wälder intensiven menschlichen Eingriffen ausgesetzt. An dieser fortschreitenden Degradation sind Waldexploitationen in besonderem Maße beteiligt, die zu fragmentierten und verschmälerten Vorkommen führen. Die noch erhaltenen Waldreste existieren an Nebenflüssen als stark degradierte Sekundärwälder, oft mit hohem Bambusanteil.

Der Wiederaufbau dieser Wälder benötigt das Wissen um Interaktionen zwischen den natürlichen Prozessen und den menschlichen Eingriffen auf der Grundlage dieser azonalen Standortbedingungen. Die vorliegende Untersuchung verbindet Untersuchungen der Vegetationgesellschaften, Analysen der Bestandesstruktur und -dynamik der flußbegleitenden Wälder mit pflanzlichen Reaktionen auf die Standortverhältnisse in den Lokalitäten Tuan Dao und Khe Ro in NO Vietnam.

Die Methodik läßt sich in 5 Bereiche untergliedern: 1) Bestandesstrukturanalysen, 2) Erfassung der Naturverjüngung, 3) Jahrringanalysen, 4) Messung des pflanzen-internen Wasserhaushalts und 5) soziologische Analysen.

Unter Berücksichtigung der räumlichen Besonderheiten flußbegleitender Wälder bestand das Inventurverfahren je Lokalität aus 20 Transekten (10 m x 50 m). Die Transekte waren senkecht zum Fluß ausgerichtet und mit 150 m Zwischendistanz systematisch verteilt. Für die Strukturanalyse wurden die Brusthöhendurchmesser (BHD), die Baumhöhen, sowie die Entfernung vom Fluß für alle Bäume ≥ 5 cm BHD erfaßt.

Die Verjüngung wurde je Lokalität auf einhundert 5 m x 5 m Unterflächen aufgenommen und in Sämlinge (≤ 30 cm Höhe) und Jungbäume (> 31 cm < 130 cm Höhe und BHD <5 cm) stratifiziert.

Um evtl. Gradienten der Standortveränderungen mit zunehmender Distanz vom Fluß zu erkennen, wurde die Baumartenkomposition, die Bestandesstruktur und die Verjüngungsdynamik in 5 Entfernungsklassen getrennt untersucht. Darüber hinaus wurde die stark durch Überschwemmungsereignisse betroffene Zone I (1-25 m Flußentfernung) der nicht überschwemmten Zone II (25-50 m Flußentferung) gegenübergestellt.

Für die Jahrringanalysen wurden 5 Baumarten ausgewählt, die dominant und/ oder wirtschaftlich wichtig sind. Insgesamt 70 Probebäume (40 aus Tuan Dao, 30 aus Khe Ro) mit zylindrischen, geraden Stämmen und ohne sichtbare Schäden wurden mit einem PRESSLERschen Zuwachsbohrer in Brusthöhe beprobt. Die Bohrkerne wurden in Göttingen nach Standartmethoden ausgewertet.

Die Erfassung des pflanzeninternen osmotischen Potenzials erfolgte an 5 dominanten und/oder ökonomisch bedeutenden Baumarten in Tuan Dao und an 6 Arten in Khe Ro. Jeweils 6 Blattproben pro Baumart und Lokalität wurden unter Feldbedingungen gewogen, zur Vermeidung enzymatischer Veränderungen abgetötet und transport-gerecht verpackt. Die Bestimmung des Gefierpunktes des Pflanzensaftes erfolgte im Göttinger Labor.

Um die historische und rezente menschliche Einwirkungsserie auf den Wald zu erfassen wurden einige Techniken des Rapid Rural Appraisal (RRA) und des Participatory Appraisal (PRA), einschließlich sekundäre Daten-Auswertungen, direkte und teilnehmende Beobachtung, semi-strukturierte Interviews und Rankingtechniken verwendet.

Folgende Hauptergebnisse wurden erzielt

- Die Untersuchungsbestände sind durch menschlicher Nutzung unterschiedlich stark degradiert. Trotz gesetzliches Verbotes wurden und werden Bauholz, Brennholz, Bambus eingeschlagen und Nicht-Holzprodukte gesammelt. Die angrenzenden Gemeinden erkennen zunehmend die Schutzfunktion dieser Wälder (Kapitel 4.1).

- Das systematische Transektdesign ist für die Waldinventur dieser schmalen, flußbegleitenden Waldstreifen sehr geeignet. Die Positionsbestimmung aller Bäume ≥ 5 cm BHD ist eine wichtige Grundlage für die Analyse der Vegetationsänderung in verschiedenen Entfernungen vom Fluß.

- Der Stichprobenumfang ist ausreichend, die Artenarealkurven flachen sowohl in Tuan Dao als auch in Khe Ro bei 4000 m^2 Aufnahmefläche ab. Der Standartfehler der Grundflächen liegt in Tuan Dao mit $S_{\bar{x}}$ = 5,5 % und in Khe Ro mit $S_{\bar{x}}$ = 7,3 % sehr niedrig, somit repräsentierten die Stichproben den Wald sehr gut. 788 Bäume, die sich auf 92 Arten und 44 Familien verteilen, wurden in Tuan Dao gefunden. In Khe Ro ist diese Zahl mit 983 Stämmen deutlich höher, hier verteilen sich diese auf 118 Arten und 49 Familien. Viele Baumarten haben nur eine niedrige Abundanz.

- Die Diversitätsindices zeigen für beide Untersuchungslokalitäten hohe Werte. So liegt der SIMPSON-Index zwischen 0,96 bis 0,97 und der SHANNON-WIENER-Index bei 3,70 und 3,89. Die Artenvielfalt varriert mit zunehmender Entfernung von den Flüssen kaum. Tuan Dao und Khe Ro haben nur 49 gemeinsame Baumarten (Kapitel 4.2).

- Beide Untersuchungslokalitäten werden von den agressiven, schnellwüchsigen Lichtbaumarten *Macaranga denticulate, Wrightia tomentosa* und *Eurya nitida* (in Tuan Dao) und von *Engelhardta chrysolepis, Maesa balansae* und *Aporusa dioica* (in Khe Ro) dominiert. In unmittelbarer Flußnähe ist die Abundanz von Bambus besonders hoch. Dennoch ist die Artenvielfalt und Artenkomposition in unterschiedlicher Distanz vom Fluß ausglichen.

- Die quadratischen Mitteldurchmesser (d_q) und die Gesamtgrundflächen sind in Khe Ro höher als in Tuan Dao. Darüber hinaus sind die entsprechenden Durchmesser und Grundflächen im flußnahen Bereich (Zone I) höher als in weiterer Flußentfernung (Zone II). Die Stammdurchmesser des Gesamtbestandes sind abnehmend verteilt, was für Naturwälder typisch ist (Kapitel 4.4.2).

- Die Durchmesser-Höhen-Verteilung wurde mit dem Modell nach PRODAN am besten angepaßt. Der Bestand in Khe Ro zeigt einen steileren Kurvenverlauf als Tuan Dao, letzte Werte streuen stärker. Die Verteilungsmuster der verschiedenen Baumarten beider Lokalitäten werden durch unterschiedliche Modelle optimal repräsentiert (Kapitel 4.5.1).

- In Khe Ro beträgt die LOREY´sche Mittelhöhe 13,1 m, die Oberhöhe (h_0) 13,8 und die Spitzenhöhe ($\bar{h}_{100}$) 15,0 m. Dagegen liegen die Werte in Tuan Dao deutlich niedriger. 40 % der Baumarten in Tuan Dao und 48 % in Khe Ro sind vertikal durchgehend. Nur 30 % der Arten in Tuan Dao und 35 % in Khe Ro sind in der Unterschicht abundant und verjüngen sich (Kapitel 4.5.2, 4.5.3).

- Das Bestandesvolumen aller Bäume $\geq$ 5 cm BHD liegt in Tuan Dao mit 77 m^3/ha etwa halb so hoch wie in Khe Ro mit 148 m^3/ha. Auch der Volumenanteil wertvoller marktfähiger Baumarten ist in Khe Ro deutlich höher.

- In Khe Ro ist die Naturverjüngung deutlich besser. Während die wirtschaftlich wichtigen Baumarten *Vatica tonkinensis, Erythrophloeum fordii, Madhuca pasquieri, Mischocarpus oppositifolius, Lithocarpus ducampii, Castanopsis indica* als Sämlinge relative häufig sind, fehlen sie meist im Jungwuchskompartiment. Die entfernung vom Fluß hat keinen nachweisbaren Einfluß auf die Verjüngungsquantität und -qualität (Kapitel 4.7).

- Die Jahrringanalysen zeigen, daß die untersuchten Baumarten mit Zuwachs-zonierungen auf die Jahresniederschläge und die Niederschläge in der Regenzeit reagieren. Die Arten in Tuan Dao zeigen einen höheren laufenden Durchmesserzuwachs. Über die Berechnung des Volumenzuwachs konnte bestimmt werden, ob der per Verordnung festgelegte Mindesthaubarkeits-durchmesser (MHD) des polyzyklischen Nutzungssystems adaequat ist.

- Die pflanzeninternen osmotischen Potenziale ausgesuchter Baumarten liegen in diesen flußbegleitenden Wäldern besonders niedrig. So schwanken die Werte zwischen -0,14 bis -0,23 MPa in Tuan Dao und -0,17 bis -0,31 MPa in Khe Ro. Die Werte unterstreichen, daß die osmotisch wirksamen Bodenbestandteile offensichtlich vom Fließgewässer „abtransportiert“ wurde. Das bestätigt auch die direkt an Bodenproben kryoskopisch vorgenommene Bestimmung der osmotischen Bodenpotenziale. Der Vergleich der pflanzeninternen Werte mit den bodeninternen Werten zeigt eine sehr genaue Überstimmung, was die osmotische Adaptation der Pflanze an den Boden belegt.

Auf der Grundlage der Ergebnisse werden Managementstrategien für die flußbegleitenden Wälder NO-Vietnams vorgeschlagen, die eine Kombination passiver und aktiver Ansätze erfordern. Während passive Ansätze hauptsächlich den strengen Schutz im Kernschutzgebiet umfassen, müssen aktive Wiederherstellungsansätze die Anwohner einbeziehen. Dabei haben Pufferzonenentwicklung, Einbringen einheimischer marktfähiger Baumarten und die Beteiligung der Dorfbewohner an den Managementaktivitäten und den Erträgen hohe Priorität. Für die Pufferzonen-entwicklung und die Rehabilitation unterschiedlich stark gestörter Sekundärwälder ist die hier gewonnene Kenntnis der Artenzusammensetzung und die aktuelle Bestandesstruktur und -dynamik von besonderer Hilfe, da hierfürdie Anreichung mit einheimischen Wertbaumarten und die Förderung der Naturverjüngung im Vordergrund stehen muß.

8. References

AKÇA, A., 2000: Forest Inventory. Institute of Forest Management and Yield Sciences, University of Göttingen. 191 p.

ANONYMOUS, 1995: Project on Establishing Protection Forest System of Luc Nam River. Unpublished report.

ANONYMOUS, 1997: Project on Forest Resource Protection and Management of Son Dong District (1996-2005). Unpublished report.

ANONYMOUS, 1999: A report on the zoological resources of Khe Ro Nature Reserve, Bac Giang province. Xuan Mai Forestry University. Unpublished report.

ANONYMOUS, 2002a: Planning for Forestry Development of Bac Giang Province (2002 – 2010). Unpublished report.

ANONYMOUS, 2002b: Riparian Areas: Functions and Strategies for Management. http://www.nap.edu/openbook/0309082951/html/84.html. Accessed 04.2005.

ANONYMOUS, 2002c: Soil laboratory protocol of Thai Nguyen University. Unpublished report.

ANONYMOUS, 2004: Activated charcoal. http://www.emedicinehealth.com/. Accessed 09. 2002.

ANONYMOUS 2005: Sustainable Management of River Flows and Water Extractions in Vietnam. http://www.usaep.org/Resources/. Assessed 05.2005

ASSMANN, E., 1970: The principles of forest yield study. Brauschweig. 506 p.

AVERY, T. E., BURKHART, H. E., 2002: Forest Mensurement. (5. Edition), New York. 456 p.

BANG, D., LIEM, C. and THU, D.C., 1975: Script of pedology practise. Ha Noi.

BERLAGE, H.P., 1931: On the relationship between thickness of tree-rings of Djati trees and rainfall on Jawa. Tectona 24: 939-953.

BHATTACHARYYA, A., YADAV, R. R., BORGAONKAR, H. P. and PANT, G. B., 1992: Growth-ring analysis of Indian tropical trees: dendroclimatic potential. Current Science 62 (11): 736-741.

BELEM, M., 1996: Structure and dynamics of two gallery forests in the Biosphere Reserve of the Hippopotamus Pool. Proceedings of International Symposium on Assessment and Monitoring of Forests in Tropical Dry Regions with Special

Reference to Gallery Forests 04-07.11.1996. University of Brasilia, Brazil: 329-338.

BRACK, C., 1999: Lecture note ``Forest Measurement and Modelling``. http://sres.anu.edu.au/associated/mensuration/. Accessed 10.2004.

BRAGG, W. K., KNAPP, A. K. and BRIGGS, J. M., 1993: Comparative water relations of seedling and adult *Quercus* species during gallery forest expansion in tallgrass prairie. Forest Ecology and Management, 56: 29-41.

BRANDIS, D., 1898: Forsteinrichtung in den Teakwaldungen von Pegu. Allg. Forst und Jagdztg. 74: 45-52.

BRINSON, M.M., 1990: Riverine forests. In: LOGO, A.E., BRINSON, M. and BROWN, S. (eds.). Forested Wedlands. Ecosystems of the world 15: 87-141. Elsevier, Amsterdam.

BRODBECK, F., 2004: Strucutre and processes in traditional forest gardens of Central Sulawesi, Indonesia. Cuvillier Verlag Göttingen. 196 p.

CAIN, SA., de OLIVEIRA CASTRO; G.M., 1956: Application of some phytosociological techniques to Brazilian rain forest. Amer. Journal of Botany 43 (10): 911-941.

CHURCH, M., 1992: Channel morphology and typology. In: CALOW, P. and PETTS, G.E. (eds.). The River Handbook Vol. 1., Oxford: 126-143.

COOK, E. R., KAIRIUKSTIS, L. A., 1989: Methods of dendrochronology: Application in the environmental Sciences. Dodrecht, Boston, London.

COSTER, C., 1927, 1928: Zur Anatomie und Physiologie der Zuwachszonen und Jahresringbildung in den Tropen. Annales du Jardin botanique de Buitenzorg. I (37): 49-161, II (38): 1-114.

CURTIS, J.T., McINTOSH, R.P., 1951: An upland forest continuum in the prairie forest border region of Wisconsin. Ecology 32 (3): 476-496.

DEILLER, A.-F., WALTER, J.-M.N. and TRÉMOLIÈRES, M., 2001: Effect of flood interruption on species richness, diversity and floristic composition of woody regeneration in the upper Rhine alluvial hardwood forest. Regulated Rivers: Research & Management 17: 393-405.

DOUGLAS, I., 1999: Hydrological investigations of forest disturbance and land cover impacts in South-East Asia: a review. In: NEWBERY, D.M., CLUTTON-BROCK. T.H. and PRANCE, G.T. (eds.). Changes and disturbance in tropical rainforest in SE Asia. The Royal Society. Imperial College Press. 175 p.

FAO, 1990: Soil map of the world. Revised legend. FAO, Rome, Italy.

FAO, 1999: Country profiles: Forest cover- natural woody vegetation. www.fao.org/forestry/site/5966/en**.** Accessed 6.2003.

FELFILI, J. M., 1995: Diversity, structure and dynamics of a gallery forest in central Brazil. Vegetatio 117 (1): 1-15

FELFILI, J. M., 1996: Dynamics of the natural regeneration in the Gama gallery forest in central Brazil. Forest Ecology and Management 91: 235-245.

FOREST INVENTORY AND PLANING INSTITUTE (FIPI), 1995: Handbook of forest inventory and planning. Ha Noi.

FOREST SCIENCE INSTITUTE OF VIETNAM (FSIV), 1998: Results of Scientific Research on Silviculture in Vietnam. Ha Noi.

FORMAN, R.T.T. and GORDON, M., 1986: Landscape Ecology. Wiley, New York. 619 p.

FÖRSTER, M., 1973: Strukturanalyse eines tropischen Regenwaldes in Kolumbien. Allgemeine Forst-und Jagdzeitung 144. Jahrgang (1): 1-8.

FRANKLIN, D.C. and BOWMAN, D. J. S., 2004: A multi-scale biogeographical analysis of *Bambusa arnhemica*, a bamboo from monsoonal northern Australia. Journal of Biogeography 31: 1335-1353.

FRÄNZLE, O., 1977: Biophysical aspects of species diversity in tropical rain forest ecosystems. In: MÜLLER, P. (Hrsg.): Ecosystem research in South America. Biogeographica Vol. 8. The Hague, Holland. 69-83.

FREDERICK S. BAKER, F.E., 1950: Principles of silviculture. New York. 414 p.

FRIEDRICHS, J., 1990: Methoden empirischer Sozialforschung. Westdeutscher Verlag. Opladen. 429 p.

FRITTS, H.C., 1976: Tree ring and climate. London, New York, San Francisco. 567p.

FU, J., 2001: The competitive strength of moso Bamboo (*Phllostachys pubescens* Mazel ex H. de Lehaie) in the natural mixed evergreen broad-leaved forests of the Fujian Province, China. Cuvillier Verlag Göttingen, Germany. 150 p.

GERBRE, G.M., TSCHAPLINSKI, T.J., SHIRAC, T., 1998: Water relations of several hardwood species in response to through fall manipulation in an upland oak forest during a wet year. Tree physiology 18: 299-305.

GEBREHIWOT, K., 2003: Ecology and management of Boswellia papyrifera (Del.) Hochst. Dry forest in Tiray, Northern Ethiopia. Cuvillier Verlag Göttingen. 183p.

GENTRY, A.H., 1982: Pattern of neotropical plant species diversity. Evolutionary Biology 15: 1-84.

GIRMA, F.S. and KRIEG, D.R., 1992: Osmotic adjustment in Sorghum: Mechanisms of diurnal osmotic potential changes. Plant Physiology 99: 577-582.

GODOY, J.R., PETTS, G. and SALO, J., 1999: Riparian flooded forest of the Orinoco and Amazon basins: a comparative review. Biodiversity and Conservation 8: 551-586.

GODOY, J.R., PETTS, G. and KNAB-VISPO, C., 2001: Ecological gradients within the riparian forests of the lower Caura River, Venezuela. Plant Ecology 152 (1): 101-118.

GOMEZ-POMPA, A., WHITMORE, T. C., HADLEY, M. (ed.), 1991: Rain forest regeneration and management. Man and The Biosphere Series, UNESSCO, Paris: 235-256.

GOSSELINK, J.G. and TURNER, R.E., 1978: The role of hydrology in freshwater wetland ecosystems. In: GOOD, R.E., WIGHAM, D.F. and SIMPSON, R.L. (Hrsg.): Freshwater wetlands: Ecological processes and management potential. Academic Press. New York, USA: 63-68.

GOUVEIA, G. P. and FELFILI, J. M., 1999: Phenology of cerrado and gallery forest communities in central Brazil. Revista Árvore 22 (4): 443-450.

GRÄFE, W., 1981: Struktur- und Dynamikuntersuchungen in Zweitwuchsbeständen der westlichen Llanos Venezuelas. Diss. Göttingen. Germany.

GRAHLE, A., 1934: Vergleichende Untersuchungen über strukturelle und osmotische Eigenschaften der Nadel verschiedener *Pinus*- Arten. Diss. Tübingen. Germany. 294 p.

GREIG-SMITH, P., 1983: Quantitive plant ecology. 3rd eds.. Studies in Ecology Vol. 9. Oxford. 359 p.

GÜNTER, S., 2001: Ökologie und Verjüngung von Mahagoni (*Swietenia macrophylla* King) in Naturwäldern Boliviens. Cuvillier Verlag Göttingen. 185p.

HALLÉ, F., OLDEMAN, R.A.A., TOMLINSON, P.B., 1978: Tropical Trees and Forests: An Architectural Analysis. Springer. Berlin-Heidelberg-New York. 431 p.

HEARTSILL-SCALEYY, T. and AIDE, T.M., 2003: Riparian vegetation and stream condition in a tropical agriculture-secondary forest mosaic. Ecological Applications 13 (1): 225-234.

HUSCH, B., 1963: Forest mensuration and statistics. The Roland Press Company. New York. 474 p.

IMAÑA-ENCINAS, J. , 2002: Personal communication. Göttingen.

IRMLER, U., 1977: Inundation forest types in the vicinity of Manaus. In: P. MÜLLER (eds.). Ecosystem research in South America, Biogeographica 8: 17-29. Junk, The Hague.

KELLMAN, M., TACKABERRY, R., BROKAW, N. and MEAVE, J., 1994: Tropical gallery forests. Research & Exploration 10 (1): 92-103.

KELLMAN, M., TACKABERRY, R., 1997: Tropical environments: The functioning and management of tropical ecosystems. London and New York. 380 p.

KELLMAN, M. and MEAVE, J., 1997: Fire in the tropical gallery forests of Belize. Journal of Biogeography 24 (1): 23-34.

KELLMAN, M., TACKABERRY, R. and RIGG, L., 1998: Structure and function in two tropical gallery forest communities: implications for forest conservation in fragmented systems. Journal of Applied Ecology 35: 195-206.

KLEINN, C., 2005: Personal communication. Göttingen.

KRAMER, H., 1988: Waldwachstumlehre. Hamburg und Berlin. 367 p.

KRAMER, H., AKCA, A., 1982: Leitfaden zur Waldmeßlehre. Frankfurt am Main. 266 p.

KRAMER, H., AKCA, A., 1987: Leitfaden zur Dendrometrie und Bestandes-inventur. Second Edition. Frankfurt am Main. 287 p.

KRAMER, P. J. and BOYER, J. S., 1995: Water relation of plants and soils. USA. 495 p.

KREEB, K.H., 1990: Methoden zur Pflanzenökologie und Bioindication. Stuttgart, Germany. 327 p.

KYAW, N. N., 2003: Site influence on growth and phenotype of Teak (*Tectona grandis* Linn. f.) in natural forests of Myanmar. Cuvillier Verlag Göttingen. 163 p.

JEAN, M. and BOUCHARD, A., 1996: Tree ring analysis of wetlands of the upper St. Lawrence River, Quebec: Response to hydrology and climate. Canadian Journal Forest Resource 26: 482-491.

LAMPRECHT, H., 1969: Über Strukturanalysen im Tropenwald. Festschrift HANS LEIBUNDGUT. Beihelf zu Zeitschriften des Schweizerischen Forstvereins 46. 51-61.

LAMPRECHT, H., 1972: Einige Strukturmerkmale natürlicher Tropenwaldtypen und ihre waldbauliche Bedeutung. Forstwissenschaftliches Centralblatt 91(4): 270-277.

LAMPRECHT, H., 1989: Silviculture in the tropics. Eschborn, Germany. 296 p.

LARCHER, W., 1995 (3. ed.): Physiological plant ecology. Ecophysiology and stress physiology of functional groups. Heidelberg. 505 p.

LEIBUNDGUT, H., 1956: Beispiel einer Bestandesanalyse nach neuen Baumklassen. IUFRO, Oxford.

LIEBERMAN, D., LIEBERMAN, M., HARTSHORN, G. and PERALTA, R., 1985: Growth rates and age-size relationships of tropical wet forest trees in Cost Rica. Journal of Tropical Ecology 1: 97-109.

LUGO, A. E., BRINSON, M. and BROWN, S. (ed.), 1990: Ecosystems of The World 15: Forested Wetlands. New York. 527 p.

LUND, H. G., 1997: A primer on designing arid land and gallery forest resources inventories. Proceedings of International Symposium on Assessment and Monitoring of Forests in Tropical Dry Regions with Special Reference to Gallery Forests 04-07.11.1996. University of Brasilia, Brazil: 23-39.

LYKKE, A. M. and GOUDIABY, A., 1999: Structure, floristic composition, and conservation potentials of a remnant gallery forest at 'Mare du Dragon', Senegal. Nordic Journal of Botany 19 (5): 561-574.

MACDONALD, E. et al., 2004: Should riparian buffers be part of forest management based on emulation of natural disturbance? Forest Ecology and Management, 187: 185-196.

MAGURRAN, A.E., 1988: Ecological diversity and its measurement. Princeton.

MALANSON, G. P., 1993: Riparian landscapes. Cambridge. 296 p.

MANOKARAN, N. and KOCHUMEN, K.M.,1987: Recruiment, growth and mortality of tree species in a lowland dipterocarp foresz in Penisular Malaysia. Journal of Tropical Ecology 3: 315-330.

MARIMON, B.S. et. al., 1997: Structure of a monodominant forest of *Brosimum rubescens* Taub. In Nova Xavantina - MT, Brazil. In: Proceedings of International Symposium on Assessment and Monitoring of Forests in Tropical Dry Regions with Special Reference to Gallery Forests. University of Brasilia, Brazil. 231-238.

MEDLEY, M.E., 1992: Patterns of forest diversity along Tana river, Kenya. Journal of Tropical Ecology 8: 358-371.

MEIRA-NETO, J. A. A. et. al.,1997: Structure of a tropical riverine forest area directly affected by the hydroelectric power station at Pilar, Ponte Nova County, Minas Gerais State. Revista Árvore 21 (2): 213-219.

MELEASON, M. A., QUINN, J. M., 2004: Influence of riparian buffer width on air temperature at Whangapoua Forest, Coromandel Peninsula, New Zealand. Forest Ecology and Management, 191: 365-371.

MERCKER, H., VU, P.H. (eds.), 1993: Environmental policy and management in Vietnam. Berlin.

MEYER, H. A., 1952: Structure, growth and drain in balanced uneven-aged forests. Journal Forestry 50: 85-92.

MINISTRY OF AGRICULTURE AND FORESTRY (MARD), 2000: The names of forest plants in Vietnam. Hanoi. 460 p.

MINISTRY OF AGRICULTURE AND FORESTRY (MARD), 2001: Instructions of silvicultural technical norms. Hanoi.

MITSCHERLICH, G., 1978: Wald, Wachstum und Umwelt: Eine Einführung in die ökologischen Grundlagen des Waldwachstums Vol. 1. Frankfurt am Main. 144p.

MITLÖHNER, R., 1997a: Using trees as indicators of environmental conditions by their internal water status. Plant Research and Development 45: 35–50.

MITLÖHNER, R., 1997b: Plant water relations as indicator of forest types as site conditional tested in the Paraguan Chaco. Proceedings of International Symposium on Assessment and Monitoring of Forests in Tropical Dry Regions with Special Reference to Gallery Forests 04-07.11.1996. University of Brasilia, Brazil: 125–134.

MITLÖHNER, R., TAM, T.Q and WEIDELT, H.-J., 1997: Waldtypenbildung und Wasserverfügbarkeit im Monsunwald des südöstlichen Vietnam. Forstarchiv 68: 244-250.

MITLÖHNER, R., 1998: Pflanzeninterne Potentiale als Indikatoren für den tropischen Standort. Aachen, Germany. 238 p.

MITLÖHNER, R., 2000: Site conditions reflected by the internal water status of trees. In: BRECKLE, S.W., SCHWEIZER, B., ARNDT, U. (eds.). Results of Worldwide Ecological Study. Hohenheim, Germany: 383-389.

MITLÖHNER, R., 2002: Personal communication. Göttingen.

MORAIS, R. and SCHEUBER, M., 1996. Statistical precision in phytosociological surveys. Comparison of dynamics of two gallery forests in central Brazil. Proceedings of International Symposium on Assessment and Monitoring of

Forests in Tropical Dry Regions with Special Reference to Gallery Forests 04-07.11.1996. University of Brasilia, Brazil: 135-146.

MÜLLER-STOLL, R. W., LERCH, G., 1993: Osmotischer Wert und Wasserdefizit bei Pflanzen verschiedener ökologischer Gruppen. Archener Freunde Naturg. Mecklb. XXXII: 147-156.

NAIMAN, R.J and DECAMPS, H., 1997: The ecology of interfaces: Riparian Zones. Annual Reviews of Ecology Systems 28: 621-658.

NATTA, A.K., 2003: Ecological assessment of riparian forests in Benin: Phytodiversity, phytosociology and spatial distribution of tree species. PhD. Thesis Waeningen University. Waeningen, Netherland.

NGUYEN, V. S., 2000: Sukzessionsuntersuchungen in den Sekundärwäldern auf aufgegebenen Reisanbau- und Siedlungsflächen in Norden Vietnams. Göttinger Beiträger zur Land- und Forstwirtschaft in den Tropen und Subtropen, Heft 140. 116 p.

NYLAND, R.D., 2002 (2. Edition): Silviculture: Concepts and applications. New York. 682 p.

POEL, P. V. and NGUYEN, D.K., 1993: Land use in the Song Da Watershed (North-West of Vietnam). Social Forestry Development Project (SFDP) Song Da baseline study No. 2. Hanoi.

PAGEL, H. et. al., 1982: Pflanzennährstoffe in tropischen Böden – Ihre Bestimmung und Berwertung. VEB Deutscher Landwirtschaftsverlag. Berlin. 272 p.

PANCEL, L., (ed.), 1993: Tropical forestry handbook. Vol. 1. Berlin, Heidelberg.

PAULA, J. E., IMAÑA-ENCINAS, J. and PEREIRA, B. A. S., 1996: Wood volume and biomass of the gallery forest at the Córrego dos Macacos. Cerne 2 (2): 91-105.

PFEFFER, W., 1877: Osmotische Untersuchungen. Leipzig.

PHILIP, M. S., 1994: Measuring trees and forests (second edition). Wallingford, Oxon, UK.

PIELOU, E.C., 1969: An introduction to mathematical ecology. Wiley, New York. 385 p.

PIESCH, R., 2000: Untersuchungen zu Strurktur und Dynamik eines exploitierten Naturwaldes am Beispiel des FORÊT CLASSÉE DE LA MONDAH in GABUN. Göttinger Beiträger zur Land- und Forstwirtschaft in den Tropen und Subtropen, Heft 139. 207p.

PRANCE, G.T., 1979: Notes on the vegetation of Amazonia III: The terminology of Amazonian forest types subject to inundation. Brittonia 31 (1):26-38.

PRODAN, M., 1965: Holzmeßlehre. Frankfurt a. Mai.

PUMIJUMNONG, N., 1999: Climate-growth relationship of teak (*Tectona grandis* Linn. f.) from Northern Thailand. In: Tree-Ring Analysis – Biological, Methodological and Environmental Aspects (R. Wimmer and R.E. Vetter (eds.)). CAB International: 155-168.

QUINN, J. M. et al., 2004: Riparian buffers mitigate effects of pine plantation logging on New Zealand streams. In: Forest Ecology and Management: 191. 129-146.

RICHARD, P.W., 1996: The tropical rain forest. 2nd eds.. Cambridge, UK. 575 p.

RICHTER, F., 1998: Struktur und Dynamik flußbegleidender Wälder im Bereich des mittleren Mahakam-Beckens in Ostkalimantan, Indonesian. Göttinger Beiträger zur Land- und Forstwirtschaft in den Tropen und Subtropen, Heft 123. 191 p.

RINN, F., 1996: Time series Analysis and Presentation (TSAP Version 3.0). Heidelberg, Germany. 262 p.

ROBERT, A., 2003: River process: An introduction to fluvial dynamics. Arnold. New York. 214 p.

SCHEUBER, M. et. al., C., 1996. Methodological conception of the survey in the gallery forest of the Bananal River at the National Park of Brasilia. Proceedings of International Symposium on Assessment and Monitoring of Forests in Tropical Dry Regions with Special Reference to Gallery Forests 04-07.11.1996. University of Brasilia, Brazil: 77-90.

SCHÖNGART, J., 2003: Dendrochronologische Untersuchungen in Überschwemm-ungswäldern der *várzea* Zentralamazonien.

SCHÖNHUTH, M. and KIEVELITZ, U., 1993: Participatory learning approaches: Rapid Rural Appraisal, Participatory Appraisal: An introduction guide. Schrifftenreihe der GTZ 248. Wiesbaden. 137 p.

SCHITZLER, A.,1995: Community ecology of arboreal lianas in gallery forests of the Rhine valley, France. Acta Oecologica 16 (2): 219-236.

SCHWEINGRUBER, F.H., 1983: Der Jahrring: Standort, Methodik, Zeit und Klima in der Dendrochronologie. Stuttgart. 234 p.

SCOTT, D. A. (eds.), 1989: A Directory of Asian Wetlands. IUCN, Gland, Switzerland and Cambridge, UK: 753-793.

SHANNON, C.E., WEAVER, W., 1949: The mathematical theory of communi-cation. Urbana.

SILVA JÚNIOR, M. C., FURLEY, P. A. and RATTER, J. A, 1996: Variations in tree communities and soils with slope in gallery forest, Federal District, Brazil. Advances in hillslope processes 1: 451-469.

SIMPSON, E.H., 1949: Measurement of diversity, Nature 163. 688 p.

SIVANANTHAWERL, T., 2001: Growth and site conditions of *Ecalyptus grandis* in Sri Lanka. Cuvillier Verlag Göttingen, Germany. 128 p.

SMITH, D. C. et. al., 1998: Water relations of riparian plants from warm desert regions. Wetlands 18 (4): 687-696.

THAI, V. T., 1999: Lés Ecosystémes Forestiers Tropicaux au Vietnam. Étude de cas regional: La vegetation forestière du Vietnam. Hanoi. 298 p.

TRAN, N.P., 1975: Preliminary research on forests of Northern Vietnam. Hanoi. 212 p.

TRAN, X. T., 1994: Report on Silvicultural Characteristics of forests in the North-eastern Vietnam. FISV. Hanoi. Unpublished report.

TRAN, X.T., 2002: Personal communication. Hanoi.

URLICH, B., 1966: Kationaustauschgleichgewichte in Böden. Z. Pflanzenernährung. Bodenkunde. 113. 141-159.

VAN LAAR, A. and AKÇA, A., 1997: Forest Mensuration. Cuvillier Verlag, Göttingen. 418 p.

VANDEKERKHOVE, K., WULF, R. and CHINH, N. N., 1993: Dendrological composition and forest structure in Nam Bai Cat Tien National Park, Vietnam. Silva Gandavensis 58. pp. 41-83.

VARGHESE, V. and KUMAR, M., 1997: Ecological observations in the fresh water swamp forests of sounthern Kerala, India. Journal of tropical forest science 9 (3). 299-314.

VON WILLERT, D. J. et. al. , 1995: Experimetelle Pflanzenökologie. Stuttgart. New York, Germany.

VU, T. Q. A., 1999 : Waldzerstörung im Einzuggebiet des Cam Son-Sees, Provinz Bac Giang, Vietnam : Ursachen, Folgen und Lösungsansätze. MSc thesis, Inst. of Nature Conservation and Forest Policy, University Göttingen, Germany.

VU, T. Q. A., WORBES, M. and MITLÖHNER, R., 2003: Tree Growth Dynamics of Two Natural Secondary Gallery Forest Stands in West Yen Tu Reserve, Northeast Vietnam. Paper presented at the conference on Technological and Institutional Innovations for Sustainable Rural Development, Deutscher Tropentag 2003, Göttingen, Germany. (http://www.tropentag.de/2003/-abstracts/full/122.pdf).

WALTER, H. and LIETH, H., 1967: Klima-Diagram-Atlas. Jena.

WALTER, H. and KREEB, K., 1970: Die Hydratation und Hydratur des Protoplasmas der Pflanzen und ihre öko-physiologishe Bedeutung. Wien.

WEIDELT, H. -J., 2000: Lecture notes on tropical Silviculture I and II. Institute of Silviculture, Sec. II: Tropical Silviculture, Göttingen University, Germany. Unpublished.

WELCOMME, R.L., 1979: Fischeries Ecology of Floodplain rivers. New York.

WHITMORE, T.C., 1984: Tropical rain forests of the far east. 2. eds.. Oxford.

WHITMORE, T.C., 1991: Tropical rain forest dynamics and itsimplications for management. In: GO'MEZ-POMPA, A., WHITMORE, T. C., HADLEY, M. (ed.), 1991: Rain forest regeneration and management. Man and The Biosphere Series, UNESSCO, Paris: 67-89.

WIMMER, R. and VETTER, R. E., 1999: Tree-Ring Analysis: Biological and Environmental Aspects. CABI Publishing, UK.

WORBES, M., 1985: Structural and other adaptations to longterm flooding by trees in Central Amazonia. Amazoniana IX (3): 459-484.

WORBES, M., 1986: Lebensbedingungen und Holzwachstum in zentralamazonischen Überschwemmungswäldern. Scripta Geobotanica 17: 1-112.

WORBES, M., 1995: How to measure growth dynamics in tropical tree - a review. IAWA J. 16: 337-351.

WORBES, M., 1996: Rhythmisches Wachstum und anatomisch-morphologische Anpassungen an Lebensstrategien von Bäumen in zentralamazonischen Überschwemmungswäldern. Mitt. Deutsch. Dendrol. Des. 82: 155-172.

WORBES, M., 1999: Annual growth rings, rainfall-dependent growth and long-term growth patterns of tropical trees from the Caparo Forest Reserve in Venezuela. Journal of Ecology 87: 391-403.

WORBES, M., 2001: Short script on Forest Growth in the Tropics. Freiburg.

WORBES, M., 2002: One hundred years of tree-ring research in the tropics – a brief history and an outlook to future challenges. Dendrochronologia 20 (1-2): 217-231.

WORBES, M. et. al., 2003. Tree ring analysis reveals age structure, dynamics and wood production of a natural forest stand in Cameroon. Forest Ecology and Management 173: 105-123.

ZHANG, J., NGUYEN, T.H. and BLUM, A., 1999: Genetic analysis of osmotic adjustment in crop plant. Journal of experimental botany 50 (332): 291-302.

9. Appendices

Appendix 1 List of tree species in natural secondary riparian forest of Tuan Dao

Family	Scientific name	Vernacular name
Actinidiaceae	*Saurauja petelotii* Merr.	Nong la to
Anacardiaceae	*Toxicodendron succedanea* (L.) Mold.	Son
Anonaceae	*Xylopia vielana* Pierre.	Sai
Apocynaceae	*Alstonia scholaris* (L.) R. Br.	Sua
Apocynaceae	*Wrightia tomentosa* Roem. Ct Schult.	Thung muc long
Araliaceae	*Trevesia palmata* (Roxb. ex Lindl.) Visan.	Du du rung
Asteraceae	*Vernonia arborea* Ham.	Bong bac
Burseraceae	*Canarium tonkinensis* Engl.	Tram chim
Burseraceae	*Canarium nigrum* Engl.	Tram den
Burseraceae	*Canarium bengalense* Roxb.	Tram hong
Burseraceae	*Canarium album* Raeusch	Tram trang
Caesalpiniaceae	*Erythrophloeum fordii* Oliver	Lim xanh
Clusiaceae	*Garcinia oblongifolia* Champ.	Bua
Clusiaceae	*Garcinia* sp.	Bua vang
Datiscaceae	*Tetrameles nudiflora* R. Br.	Thung
Dilleniaceae	*Dillenia heterosepala* Finet et Gapnep	Long Bang
Dipterocarpaceae	*Vatica tonkinensis* A. Chev.	Tau mat
Ebenaceae	*Diospyros* sp.	Hong rung
Elaeocarpaceae	*Elaeocarpus griffithii* Mast.	Com
Elaeocarpaceae	*Elaeocarpus dubius* A.DC.	Com tang
Elaeocarpaceae	*Elaeocarpus* sp.	Com trang
Elaeocarpaceae	*Elaeocarpus floribundus* Blume	Com trau
Euphorbiaceae	*Mallotus hookerianus* (Seem.) Muell-Arg.	Ba bet long dung
Euphorbiaceae	*Macaranga denticulata* Muell-Arg.	Ba soi
Euphorbiaceae	*Sauropus grapdifolius* var tonkinensis Baill	Ngot rung la to
Euphorbiaceae	*Phyllanthus reticulata* Poir.	Phen den
Euphorbiaceae	*Aporosa dioica* (Roxb.) Muell-Arg.	Thau tau goc khac
Euphorbiaceae	*Endospermum chinensis* Benth.	Vang trung
Fabaceae	*Ormosia pinata* (Lour.) Merr.	Rang rang xanh
Fagaceae	*Catanopsis boisii* Hickel & A. Camus	De bac giang
Fagaceae	*Quercus platicalyx* Hickel et A. Camus	De cau
Fagaceae	*Quercus pseudo* Cornea	De cuong
Fagaceae	*Castanopsis fissa* Rehd. Et Will	De dau nut
Fagaceae	*Lithocarpus ducampii* A. Camus	De do
Fagaceae	*Quercus bella* Chun & Tsiang	De qua bet
Fagaceae	*Lithocarpus proboscideus* A. Camus	De trang
Fagaceae	*Lithocarpus pseudosundaicus* A. Camus	De xanh
Fagaceae	*Quercus poilanei* Hickel & A. Camus	Soi ao toi

Appendix 1 (*continued*)

Family	Scientific name	Vernacular name
Hypericaceae	*Cratoxyloum pruniflorum* Kurz.	Thanh nghanh
Ixonanthaceae	*Ixonanthes cochinchinensis* Pierre	Ha nu
Juglandaceae	*Engelhardta chrysolepis* Hance.	Cheo tia
Juglandaceae	*Englhardtia spicata* Blume	Cheo trang
Lauracae	*Machilus odoratissima* Nees	Re vang
Lauraceae	*Litsea baviensis* Lecomte.	Boi loi Ba Vi
Lauraceae	*Caryo daphnopsis tonkinensis* (H.Lec) Airy - Shaw.	Ca lo
Lauraceae	*Phoebe cuneata* BI.	Khao
Lauraceae	*Litsea cubeba* (Lour) Peis	Man tang
Lauraceae	*Cinamomum obtusifolium* Nees	Re gung
Lauraceae	*Machilus leptophylla* Hand.-Mazz.	Re nhot
Magnoliaceae	*Michelia balanse* (A.DC.) Dandy.	Gioi long
Melastomataceae	*Memecylon scutelletum* (Lour.) Naud.	Sam ram
Meliaceae	*Dyosxylum cauliflorum* Hiern.	Dinh huong
Meliaceae	*Toona surenii* (Blume) Merr.	Lat khet
Meliaceae	*Chisocheton paniculatus* (Roxb.) Hiern.	Quech tia
Mimosaceae	*Cylindrokelupha chevalierii* Kosterm.	Cut ngua
Mimosaceae	*Maesa balansae* Merr.	Don nem
Mimosaceae	*Pithecellobium clypearia* Benth. var. acuminatum G.	Man dia
Moraceae	*Ficus hispida* L. f.	Ngai
Moraceae	*Ficus hirta* Vahl	Vu bo
Myristicaceae	*Knema corticosa* Lour.	Mau cho la nho
Myristicaceae	*Knema pierrei* Warb.	Mau cho la to
Myrtaceae	*Syzymgium* sp.	Gioi rung
Myrtaceae	*Syzygium jambos* var. sylvaticum Merr. & Perry.	Tram do
Myrtaceae	*Syzygium brachyata* Roxb.	Tram tia
Myrtaceae	*Cleistocalyx* sp1.	Voi chim
Poaceae	*Noehouzeaua dulloa* (Gamble) A. Camus	Nua
Poaceae	*Lingnania chungii* McClure	Dung nha
Poaceae	*Ampelocalamus patelleris* (Gamble) Stapleton.	Giang
Rhizophoraceae	*Carallia diplopelata* Hand.-Mazz.	Rang ca
Rosaceae	*Pygeum arboreum* Endl.	Xoan Dao
Rubiaceae	*Wendlandia paniculata* (Roxb.) A. DC.	Hoac quang
Rutaceae	*Melicope pteleifolia* Hartl.	Ba chac
Rutaceae	*Acronychia pedunculata* (L.) Miq.	Buoi bung
Sapindaceae	*Mischocarpus oppositifolius* (Lour.) Merr.	Truong cuong
Sapindaceae	*Nephelium chryseum* Bl.	Vai guoc
Sapindaceae	*Nephelium chryseum* Blume	Vai thieu rung
Sapintaceae	*Pometia pinnata* Forst.	Sang
Sapotaceae	*Madhuca pasquieri* H. J. Lam	Sen mat
Sarcospermaceae	*Sarcosperma tonkinensis* H. Lee	Nong
Symplocaceae	*Symplocos cochinchinensis* (Lour.) Moore	Dung san

Appendix 1 (*continued*)

Family	Scientific name	Vernacular name
Theaceae	*Camellia sasamqua* Naika	Che rung
Theaceae	*Eurya nitida* Korth	Sum
Theaceae	*Schima superba* Gardn. et Champ	Voi thuoc
Tiliaceae	*Triumfetta pilosa* Roth	Ke long
Tiliaceae	*Microcos paniculata* L.	Me co ke
Ulmaceae	*Gironniera subaequalis* Planch	Ngat
Verbenaceae	*Gmelina arborea* Roxb.	Loi tho

Appendix 2 List of tree species in natural secondary riparian forest of Khe Ro

Family	Scientific name	Vernacular name
Anacardiaceae	*Toxicodendron succedanea* (L.) Mold.	Son
Anonnaceae	*Xylopia vielana* Pierre.	Sai
Araliaceae	*Schefflera heptaphylla* (L.) Frodin	Chan chim
Arecaceae	*Caryota urens* L.	Moc
Asteraceae	*Vernonia arborea* Ham.	Bong bac
Bignoniaceae	*Fernandoa brilletii* (Dop) Steen	Dinh thoi
Bignoniaceae	*Oroxylum indicum* (L.) Vent.	Nuc nac
Burseraceae	*Canarium album* Raeusch	Tram trang
Burseraceae	*Garuga pinnata* Roxb.	Tram mao
Burseraceae	*Canarium bengalense* Roxb.	Tram hong
Caesalpiniaceae	*Erythrophloeum fordii* Oliver	Lim xanh
Caesalpiniaceae	*Neonauclea purpurea* (Roxb.) Merr.	Vang kieng
Caesalpiniaceae	*Pelthophorum tonkinensis* A. Chev.	Lim xet
Clusiaceae	*Garcinia oblongifolia* Champ.	Bua
Clusiaceae	*Garcinia* sp.	Bua dai
Daphniphyllacea	*Daphniphyllum atrobadium*	Vai
Datiscaceae	*Tetrameles nudiflora* R. Br.	Thung
Dilleniaceae	*Dillenia heterosepala* Finet et Gapnep	Long bang
Dipterocarpaceae	*Vatica tonkinensis* (Griff.) Sym.	Tau mat
Dipterocarpaceae	*Parashorea chinensis* Wang Hsie	Cho chi
Elaecarpaceae	*Elaeocarpus* sp.	Com trang
Elaecarpaceae	*Elaeocarpus dubius* A. DC	Com tang
Elaeocarpaceae	*Elaeocarpus griffithii* Mast.	Com
Euphorbiaceae	*Aporusa dioica* (Roxb.) Muell-Arg.	Thau tau goc khac
Euphorbiaceae	*Bischofia trifoliata* (Roxb.) Hook.	Nhoi
Euphorbiaceae	*Phyllanthus reticulata* Poir.	Phen den
Euphorbiaceae	*Paracleissthus tonkinensis*.	Coc rao
Euphorbiaceae	*Mallotus contubernalis* Hance	Don xuong
Euphorbiaceae	*Antidesma ghasembilla* Gaertn.	Choi moi
Euphorbiaceae	*Syzygium cummi* Skulz	Trau
Euphorbiaceae	*Bridelia monoica* (Lour.) Merr.	Dom long
Euphorbiaceae	*Baccaurea sapida* Muell-Arg.	Dau da dat
Euphorbiaceae	*Epiprinus siletianus* (Baill.) Croiz.	La khom
Euphorbiaceae	*Claoxylon indicum* (Blume.) Endl. ex Hassk	Loc mai la to
Euphorbiaceae	*Sauropusgrandifolius var. tonkinensis* Baill	Ngot rung la to
Fabaceae	*Aeschynomene americana* L.	Rut nuoc
Fabaceae	*Ormosia pinata* (Lour.) Merr.	Rang rang xanh
Fagaceae	*Catanopsis indica* A.DC	De gai
Fagaceae	*Lithocarpus ducampii* (Hickel & A. Camus) A.C.	De do
Fagaceae	*Quercus platicalyx* Hickel et A. Camus	De cau
Fagaceae	*Lithocarpus tubulosus* (Hickel& A.Camus) A.C.	Soi vang

Appendix 2 (*continued*)

Family	Scientific name	Vernacular name
Fagaceae	*Lithocarpus proboscideus* (Hickel & A.Camus) A.C.	De trang
Fagaceae	*Quercus bella* Chun & Tsiang	De qua bet
Geesnericeae	*Chirifa eberhardtei* Pell	Tai voi
Hamamelidaceae	*Liquidambar formosana* Hance	Sau sau
Hypericaceae	*Cratoxylum polyanthum* Korth.	Thanh nghanh
Hypericaceae	*Cratoxylon prunifolium* Dyer.	Do ngon
Ixonanthaceae	*Ixonanthes cochinchinensis* Pierre	Ha nu
Juglandaceae	*Engelhardta chrysolepis* Hance.	Cheo tia
Juglandaceae	*Engelhardtia spicata* BI.	Cheo long
Juglandaceae	*Englhardtia spicata* Blume	Cheo trang
Lauraceae	*Litsea glutinosa* C.B.Roxb	Boi loi nhot
Lauraceae	*Litsea monopetala* (Roxb.) Pers.	Boi loi la tron
Lauraceae	*Machilus odoratissima* Nees	Re vang
Lauraceae	*Machilus oreophylla* Hance	Re nui
Lauraceae	*Cinamomum tetragonum* A. Chev	Re hong
Lauraceae	*Cinamomum bejolghota* (Buch.-Ham. Ex Nees) Sweet	Re bau
Lauraceae	*Neolitsea umbelliflora* Bl.	Khao suoi
Lauraceae	*Machilus* sp2.	Khao trang
Lauraceae	*Machilus leptophylla* Hand.-Mazz.	Re nhot
Lauraceae	*Machilus* sp1.	Khao thoi
Lauraceae	*Machilus bombycina* King	Khao
Lauraceae	*Machilus thunbergii* Sieb. et Zuce.	Khao vong
Magnoliaceae	*Michelia mediocris* Dandy	Gioi xanh
Melastomaceae	*Melastoma candidum* D. Don	Mua ba
Mimosaceae	*Pithecellobium clypearia* Benth. var. acuminatum G.	Man dia
Mimosaceae	*Maesa balansae* Merr.	Don nem
Mimosaceae	*Cylindrokelupha chevalierii* Kosterm.	Cut ngua
Moraceae	*Ficus glandulifera* Wall	Vo man
Moraceae	*Ficus hispida* L. f.	Ngai
Moraceae	*Ficus auriculata* Lour.	Va
Moraceae	*Taxotrophis ilicifolia* Vidal	Oro
Moraceae	*Nephelium chryseum* Bl.	Vai guoc
Moraceae	*Ficus fulva* Reinw.	Ngoa long
Moraceae	*Artocarpus tonkinensis* A. Chev	Chay
Moraceae	*Ficus hirta* Vahl	Vu bo
Myristicaceae	*Knema corticosa* Lour.	Mau cho la nho
Myristicaceae	*Knema pierrei* Warb.	Mau cho la to
Myrtaceae	*Syzygium polyanthum* (Wight) Walp.	San thuyen
Myrtaceae	*Cleistocalyx* sp1.	Voi chim
Myrtaceae	*Cleistocalyx operculatus* (Roxb.) Merr. & Perry	Voi
Myrtaceae	*Cleistocalys operculatus* Skeel.	Tram voi
Oxalidaceae	*Averrhoa carrambola* L.	Khe

Appendix 2 (*continued*)

Family	Scientific name	Vernacular name
Rhizophoraceae	*Carallia diplopelata* Hand.-Mazz.	Rang ca
Rosaceae	*Pygeum arboreum* Endl.	Xoan dao
Rubiaceae	*Psychotria reevesii* Wall.	Lau la to
Rubiaceae	*Wendlandia paniculata* (Roxb.) A. DC.	Hoac quang
Rubiaceae	*Alysicarpus vagmalis* DC	Vay oc
Rubiaceae	*Canthium dicoccum* (Gaertn.) Merr.	Xuong ca
Rubiaceae	*Morinda citrifolia* L. var. bracteata Hook. f.	Nhau
Rutaceae	*Acronychia pedunculata* (L.) Miq.	Buoi bung
Sapindaceae	*Mischocarpus oppositifolius* (Lour.) Merr.	Truong cuong
Sapindaceae	*Saraca dives* Pierre	Vang anh
Sapotaceae	*Madhuca pasquieri* H. J. Lam	Sen mat
Sapotaceae	*Xantolis cambodiana* Van Roven	Sen gang
Symplocaceae	*Symplocos laurina* Wall var acuminata Brand	Dung giay
Symplocaceae	*Symplocos cochinchinensis* (Lour.) Moore	Dung san
Symplocaceae	*Symplocos touranensis* Guill.	Dung trang
Theaceae	*Eurya persiaefolia* Gagnep.	Sum la dao
Theaceae	*Camellia siamensis* (L.) Kuntze	Che
Theaceae	*Ternstroemia gymnanthera* (Wight et Arn.) Sprague	Che hoi
Theaceae	*Schima superba* Gardn. et Champ	Voi thuoc rang cua
Theaceae	*Eurya nitida* Korth	Sum
Theaceae	*Camellia sasamqua* Naika	Che rung
Theaceae	*Eurya tokinensis* Gagnep.	Sum nhan
Theaceae	*Shima* sp.	Voi thuoc
Thymelyaceae	*Aquilaria crassna* Pierre	Tram huong
Tiliaceae	*Microcos paniculata* L.	Me co ke
Ulmaceae	*Gironniera subaequalis* Planch	Ngat

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