

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	<ul style="list-style-type: none"> Processes of erosion and deposition. Form of riparian landscapes. 	WELCOMME (1979)
Small channels Intermediate channels Large channels	<ul style="list-style-type: none"> 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	<ul style="list-style-type: none"> Hill-slope runoff of water to riparian areas. Topography and hydraulic properties of sediment. Regional climate condition. 	ANONYMOUS (2002)
Permanently flooded Periodically flooded	<ul style="list-style-type: none"> 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 morphological 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	<ul style="list-style-type: none"> • $d/D < 1$ • 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	<ul style="list-style-type: none"> • $1 < d/D < 10$ • 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	<ul style="list-style-type: none"> • $d/D > 10$ • Channel width of 20-30 m, with a corresponding bank-full discharge of 30-50 m³/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.

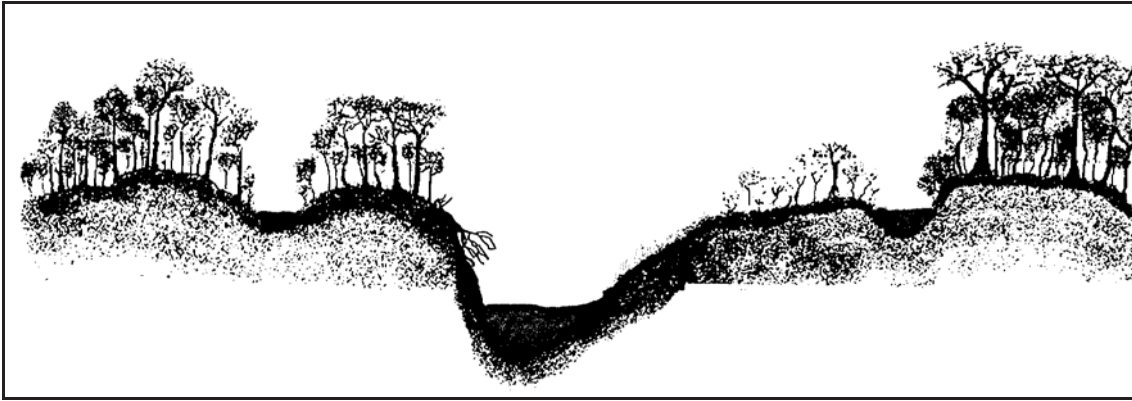


Fig. 1.1 Possible occurrence of vegetation next to water courses on different topography (BARBOSA 1997, SCHÖNGART 2003).

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 refuge 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 occurred.

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 Brasília-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. (Mimosaceae), 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 ≥ 5 cm dbh with a basal area of 12.6 m², 1062 individuals ≥ 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. (Dipterocarpaceae), *Hopea odorata* Roxb. (Dipterocarpaceae), *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,