Malaysia's policies and plans contain emphasis and provisions for holistic and integrated planning and management of natural resource and biodiversity assets as a precursor for environmentally sustainable development.

For planners, decision-makers and practitioners to meet these aspirations, resources must be viewed in a broader context. Not only must it go beyond sectors to include all stakeholders in the decision process, but it must also use the best science available to define suitable management actions.

The overall purpose of this Guideline is to support this important endeavour.

# Table of Contents

# Tables, Figures & Text Boxes

# Abbreviations

asl ......................... above sea level
cm ......................... centimetre
DID ....................... Department of Irrigation and Drainage
ha.......................... hectare
KCol..................... Kinabatangan – Corridor of Life
LK ......................... Lower Kinabatangan
km ......................... kilometre
m ........................... metre
MASMA ............... Urban Stormwater Management Manual for Malaysia
$N_2$ .......................... Nitrogen
NGO..................... Non-governmental Organisation
$NO_2$ ....................... Nitrite
$NO_3$ ....................... Nitrate
NRE ...................... Ministry of Natural Resources and Environment
NTFP..................... Non-timber forest product
P ............................ Phosphorus
USDA ................... United States Department of Agriculture
USEPA ................. United States Environmental Protection Agency

# 1 Introduction

## 1.1 Who is this Guide for?

**Term**

The Convention on Biological Diversity defines *biodiversity* as "the variability among living organisms from all sources including, *inter alia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems."

This Guideline for managing biodiversity in the riparian zone aims to assist all planners and practitioners influencing the landscape of today and tomorrow. In particular, this Guide should be useful for:

- Government agencies at the federal, state and local levels engaged in land use and natural resource planning, administration and assessment.
- Companies and small holder organisations involved in extensive land use systems such as plantations, urban development and sand mining.
- Non-governmental Organisations (NGOs), consultants, educational centres and members of civil society with an interest in biodiversity, environment and sustainable development.

## 1.2 Purpose of this Guide

This Guide aims to provide an overview of what it takes to manage and restore biodiversity in the riparian zone. This guide will assist you in:

- Understanding the importance of riparian zones for biodiversity as well as the well-being of human populations.
- Appreciating the unique types of riparian habitats in Malaysia.
- Recognising the effects of land use change on the ecosystem functions of riparian zones.
- Incorporating key technical, practical and legal considerations required for the restoration of riparian habitats that can function as habitats and corridors for biodiversity and as buffers to protect river water quality.
- Mainstreaming biodiversity into the preparation, review and updating of Policies, Plans and Programmes.

## 1.3 Using this Guide

This Guide is part of a *Best Practice Series* produced by the Ministry of Natural Resources and Environment (NRE), Malaysia. For a complete understanding of concepts and considerations presented here, readers may consult: *A Common Vision on Biodiversity – Reference Document for Planners, Decision-Makers and Practitioners* (NRE, 2008), as well as other Guidelines produced in the *Best Practice Series*.

Other relevant documents which should be referred to are:

- Guidelines for Development of Rivers and River Reserves (DID, 2001)
- Urban Stormwater Manual for Malaysia (MASMA) - Chapters 42 and 43 (DID, 2000)

Further explanation of key concepts is provided in the End Notes. The checklist in **Appendix 2** of the Guide provides information on native plants suitable for replanting in riparian habitats.

# 2 The Riparian Zone

## 2.1 What is a riparian zone?

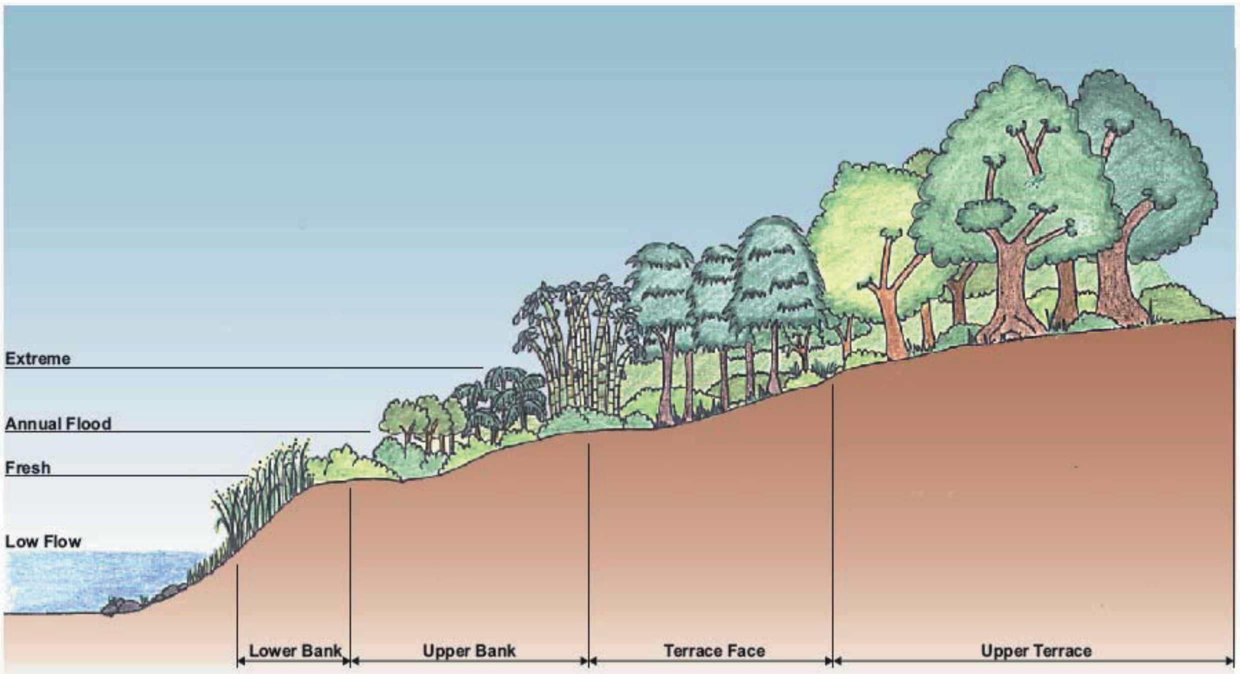
A riparian zone is essentially the land adjacent to streams and rivers; a unique transitional area between aquatic and terrestrial habitats. Plant communities in the riparian zone are called riparian vegetation.

**Term**

*Riparian* is derived from the Latin word *Ripa*, which means "river bank".

This zone may be taken to consist of four sections, each having different physical conditions, particularly in terms of exposure to water currents, periodical inundation and soil type (**Figure 1**). The plants found in each section have specific adaptations which enable them to tolerate these physical conditions:

- *Lower bank* – Constantly subjected to erosive water current. The plants here are able to survive submerged underwater for extended periods of time, with root systems that are able to hold the soil in place.
- *Upper bank* – Occasionally subjected to erosive water current. The plants here are tolerant to sporadic inundation.
- *Terrace face* – Only subjected to inundation during high flow events, such as annual flooding. The plants here range from wetland to dryland species.
- *Upper terrace* – Only subjected to extreme high flow events, such as 1 in 100 year floods. The plants here are mainly dryland species.




Drawing by Fong Chuen Far

**Figure 1.** Cross section of a riparian zone.

## 2.2 Why is the riparian zone important?

> **Terms**
>
> An *ecosystem* is a dynamic complex of plant, animal, and microorganism communities and the nonliving environment, interacting as a functional unit. Humans are an integral part of ecosystems.
>
> *Ecosystem services* are the benefits that people obtain from ecosystems.

Although constituting only a small part of the landscape, riparian zones that are intact and functional are important habitats for biodiversity and provide **ecosystem services**[1] which are essential to the well-being of human populations. The main functions of riparian zones are:

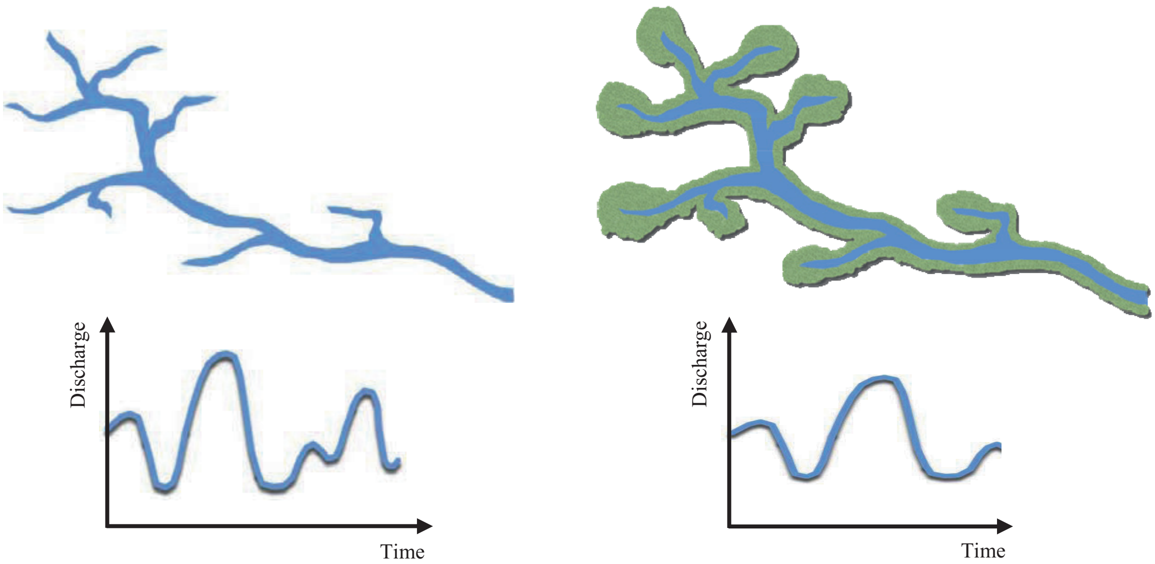
*Water quality improvement*

**Non-point sources** of pollution, including runoff from agriculture lands and plantations, construction sites and failed septic tanks, introduce a variety of pollutants into the river system. These pollutants, which include sediments, nutrients, organic wastes, chemicals and metals, are difficult to control, measure and monitor (**Table 1**).

Riparian zones serve as buffers which intercept non-point sources of pollution. In particular, riparian vegetation absorb the heavy metals and nutrients, trap sediments suspended in surface runoff and provide a habitat for micro-organisms that help break down the pollutants. In plantations where fertiliser, pesticides and herbicides are used, the maintenance of a vegetated riparian buffer strip of sufficient width is therefore extremely important to minimise the amount of these pollutants that enter the rivers.

*Flood mitigation*

Riparian vegetation increases surface and channel roughness, which serves to slow down surface water that enters the river and reduce flow rates within the river. This helps to slightly alleviate the magnitude and intensity of flooding downstream (**Figure 2**). However, it should be noted riparian vegetation is by no means a viable solution to flood woes – this requires good management of entire river basins, especially the upstream catchments.




(b) Downstream discharge without riparian vegetation

(a) Downstream discharge with riparian vegetation

**Figure 2.** Effect of riparian vegetation on downstream discharge.

*Riverbank stabilisation*

Riparian vegetation protects the riverbanks from erosion or scouring caused by rain, water flow, etc. Erosion caused by removal of riparian vegetation results in sedimentation of the river which increases flood levels, as well as bank failure, which brings about the need for expensive remediation measures such as dikes, levees and flood walls.

*Cultural/recreational values*

Vegetated riparian zones, especially in urban areas, are important open spaces that may be utilised for recreational and aesthetic purposes such as walking/cycling trails or picnic areas. Numerous studies demonstrate that linear parks not only improve the quality of life in communities, but can increase nearby property values that in turn increase local tax revenues (McMahon, 1994). Rivers also play an important role in many cultures and traditions.

*Prime wildlife habitats*

Riparian habitats are unique ecosystems where terrestrial and aquatic plant communities meet. The unique micro-climate and proximity to water make riparian zones excellent habitats for many species of animals, especially birds and amphibians. In addition, salt licks, which are an important source of nutrients for ungulates are usually found in the vicinity of rivers and streams.

*Natural wildlife corridors*

Riparian zones are a critical component in landscape ecology as they are natural corridors which link landscapes across regions, from the upland headwaters to the floodplains in the lowland. Corridors have several critical ecological functions as they serve as conduits for wildlife and consequently allow for the movement of genetic material, nutrients and energy across the landscape, in particular via pollination and seed dispersal (**Box 1**).

**Box 1. Pollination and seed dispersal**

Pollination and seed dispersal are two ecological processes that are vital to ensure the survival of plants. Consequently, they are also important for animals and the forest ecosystems as a whole, as plants are primary producers in the food chain, and form the basic structure of the forest.

In dense tropical rainforests where wind is scarce, most plants rely on animals for pollination and seed dispersal. Insects, birds and bats pollinate the plants by transferring pollen from flower to flower in their quest for food (nectar and pollen), while fruit-eating animals (frugivores) disperse seeds through the forest via their droppings. It is therefore crucial to ensure that these animals are able to move safely through the forests as well as between different patches of forest.

To complicate matters, many of these animals are specialists i.e. they only pollinate or disperse seeds of a select number of species. Consideration should also be given to the specific needs of the various species to move through or between forests.

Some animal groups which serve as pollinators:

- Insects – including bees, butterflies, moths and beetles
- Bats – particularly fruit bats
- Birds – including sunbirds, flowerpeckers and spiderhunters

Some animal groups which serve as seed dispersers:

- Fruit bats and birds
- Primates – including leaf monkeys, macaques and gibbons
- Rodents – including rats, porcupines, squirrels and flying squirrels
- Ungulates – including deer and wild boar

*Maintenance of stream ecology*

Riparian vegetation is essential to aquatic organisms. Trees and shrubs provide shade which reduces the water temperature, thus allowing many aquatic species to survive and limit the amount of light in the river which prevents excessive growth of water plants and algae.

Woody debris (known as snags) and leaf litter derived from riparian vegetation are important habitat components of rivers. Snags and leaf litter provide valuable habitats for a number of aquatic and terrestrial species: they are used as nursery areas for larvae and juvenile fish, refuge from predators, shade, feeding and spawning sites and shelter from currents.

Riparian vegetation is a source of food for aquatic animals and plants, providing fruits, insects, leaf litter and organic debris. These food sources are a major component of the diet of many species of fish and aquatic organisms such as turtles.

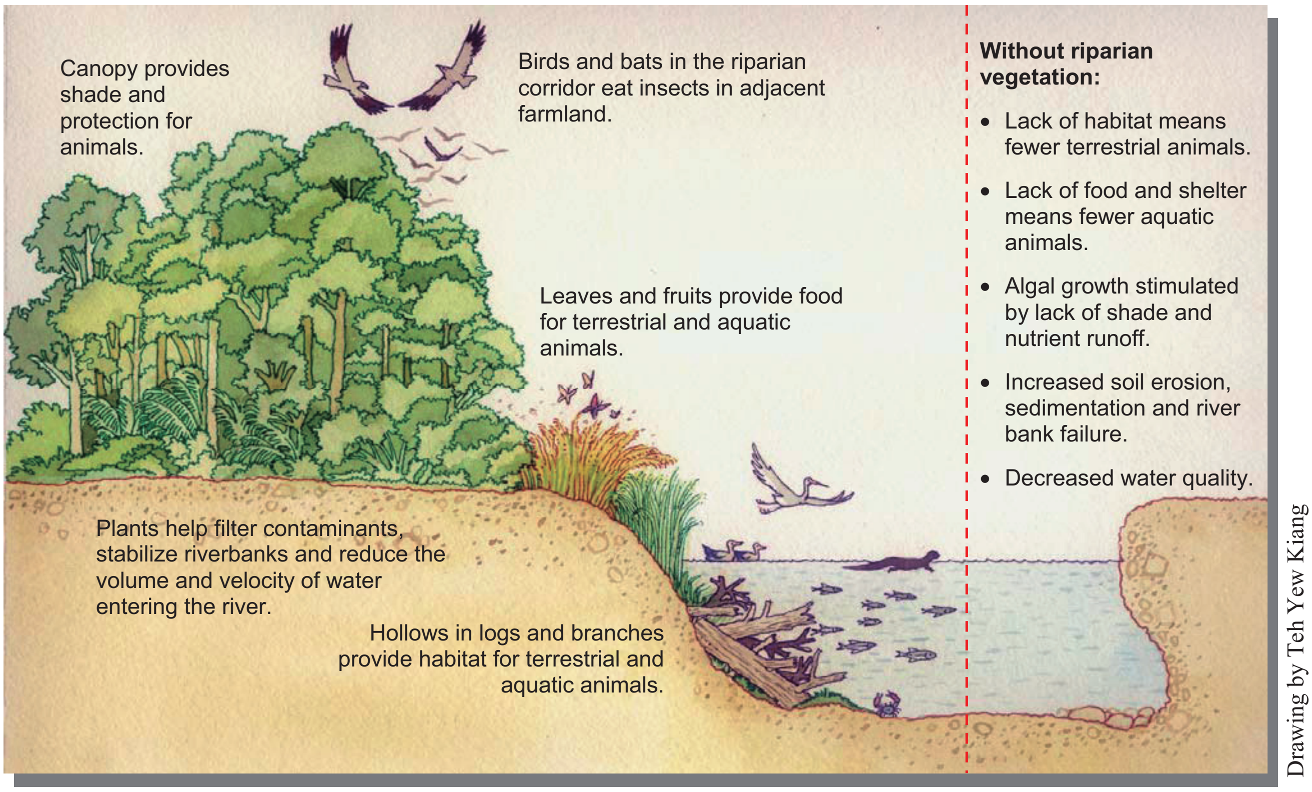



**Figure 3.** Functions of riparian vegetation.

**Table 1.** Non-point source pollutants.

| Pollutant | Sources | Effects |
|---|---|---|
| **Nutrients** | Although essential elements in aquatic ecosystems, excess amounts can be harmful to aquatic life and reduce water quality of for human use. Nutrients can enter surface waters in subsurface or surface flows; either in dissolved form (as nitrates) or attached to soil particles. Major sources of nutrients are fertilizers, sewage and manure, while industry and atmospheric deposition also contribute significant amounts of nutrients. (Gilliam et al., 1997) | The most significant impact of nutrients on rivers is eutrophication, i.e. the excessive growth of algae and other aquatic plants due to high levels of nutrients. Excessive plant growth depletes the dissolved oxygen in the water, and chokes the water body with large unsightly mats of algae and decaying organic matter. This results in water with an undesirable colour, taste and odour. Eutrophication can affect a stream's ability to support plant and animal life, interfere with water treatment and diminish its recreational and aesthetic values. Some algae may also form toxins which are directly harmful to aquatic organisms and humans. |
| **Sediment** | Sediment refers to soil particles that enter streams, lakes and other bodies of water from eroding or bare land, including plantations, construction and logging areas (especially logging roads), urban areas and eroding stream banks. | Sedimentation of rivers can have a pronounced effect on water quality and stream life. Sediment can clog fish gills, suffocate fish eggs and aquatic insect larvae and cause fish to modify their feeding and reproductive behaviours. Sediment also interferes with recreational activities as it reduces water clarity and fills in water bodies. In addition to mineral soil particles, eroding sediments may transport other substances such as animal wastes, pesticides, metals and other compounds that reduce water quality (Neary et al., 1988). |
| **Pesticides** | Pesticides enter streams through surface runoff from plantations, farms, gardens and nurseries, either dissolved in water or attached to sediment particles. They may also be discharged into streams from contaminated groundwater or be deposited into surface waters through atmospheric deposition (McConnell et al., 1995). | Pesticide uptake by human beings is mainly through the consumption of contaminated fish and shellfish, and direct consumption of contaminated water. Certain pesticides accumulate in the fatty tissues of organisms and consequently build up in higher concentrations in top predators further along the food chain, including humans. This is referred to as "biomagnification". Effects at the organism or ecological level are usually considered to be an early warning indicator of potential human health impacts. However, generalisation is difficult as different categories of pesticides have different types of effects on living organisms, many of which are chronic and not easily detected. Examples include cancers, tumours and lesions, reproductive failure, disruption of hormonal systems and physiological impacts such as physical deformities and egg shell thinning. |
| **Metals** | Metals may be released into the aquatic environment through industrial processes, mining operations, urban runoff, transportation activities and application of sewage sludge. Trace metals may also be introduced with agricultural pesticides and fertiliser. | Metals pose a particular threat to aquatic environments because they do not degrade and tend to accumulate in the bottom sediments. Metals may also accumulate in plant and animal tissues. The fate of metals in riparian areas is not well understood. |

## 2.3 Riparian habitats in Malaysia

Although no official classification exists, it should be noted that riparian habitats are not homogeneous, but have varying assemblages of plants and animals depending on factors such as elevation, soil and hydrology. Six types of riparian habitats have been distinguished in Malaysia, based on the dominant original riparian vegetation from the highlands to the sea (Corner, 1988) (**Figure 4**):

- ***Montane* streams** – Narrow, shallow fast-flowing streams found in the montane regions. These areas are usually above 1,000m asl and usually fall within forest reserves.
- ***Saraca* streams** – Found below montane streams, *Saraca* streams are rocky, fast-flowing, with waterfalls rapids down the hillsides. *Gapis* (*Saraca* spp.) trees are the dominant species, which form "tunnels" over the water.
- ***Neram* rivers** – Found downstream from *Saraca* streams, *Neram* rivers are distinguished by the abundance of *Neram* (*Dipterocarpus oblongifolius)* trees on the river banks.
- ***Rassau* rivers -** Freshwater tidal rivers connecting the rocky streams and rivers with the brackish estuaries. Distinguished by the abundance of the screwpine *Rassau* (*Pandanus* sp.).
- ***Nipah* rivers** – Found upstream of mangroves where the water is calmer with muddy substrate with regular inflow of freshwater and silt. Dominated by the *Attap* palm (*Nypa fructicans*).
- **Mangrove rivers** – Found on the lower stretches of rivers with brackish water, down to the estuaries. Dominated by mangrove species such as Bakay (*Rhizophora* spp.), *Api-api* (*Avicennia* spp.) and Berus (*Bruguiera* spp.).

In addition, peat swamps and freshwater swamps are two other unique ecosystems that are found along the lower reaches of certain rivers. Both are important ecosystems which have become scarce due to conversion for agriculture use.

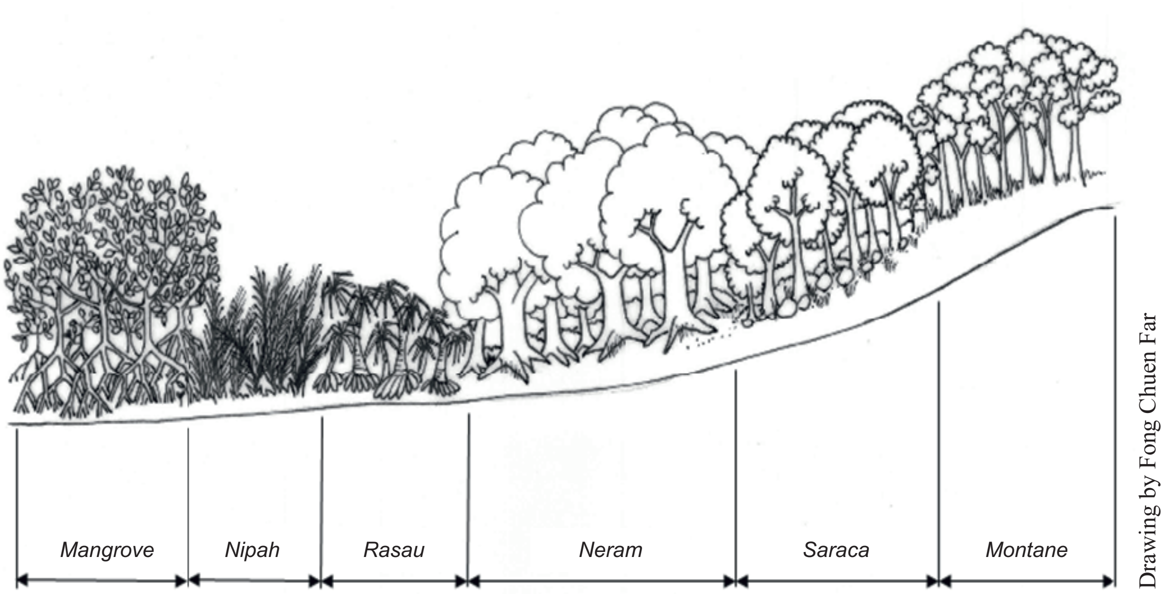



**Figure 4.** Types of riparian habitats in Malaysia.

## 2.4 What happened to the riparian zones?

Many riparian zones in Malaysia have been altered in the course of resource use or development. For example, river channels have been straightened and embankments concreted for flood mitigation. In plantations, crops have been planted right up to the river margins and in many other areas, the mining of valuable river sand has resulted in the clearing of riparian habitats.

All of these have led to altered riparian ecosystems that are no longer able to perform their beneficial functions, and have very low biodiversity value. The general impacts of human activity on the beneficial functions of the riparian zone are listed in **Table 2**.

**Table 2.** Impacts of human activities on the riparian ecosystem.

| Human Activity | Impact on Ecosystems | Services at Risk |
|---|---|---|
| Dam construction | • Alters timing and quantity of river flows<br>• Alters water temperature<br>• Hinders nutrient and sediment transport<br>• Hinders fish migration | • Riparian habitat for wildlife<br>• Riparian corridor for wildlife<br>• Water supply<br>• Flood mitigation<br>• Natural floodplain fertility<br>• Commercial fisheries<br>• Recreation |
| Dike and levee construction | • Destroys hydrologic connection between river and floodplain habitat | |
| Excessive river diversions | • Depletes streamflows to damaging levels | |
| Draining of wetlands | • Eliminates key component of the aquatic environment | |
| Deforestation/poor land use | • Alters runoff patterns<br>• Inhibits natural recharge<br>• Siltation of rivers | |
| Uncontrolled pollution | • Diminishes water quality<br>• Species health<br>• Bioaccumulation | |
| Sand mining | • Destroys riparian and benthic habitat<br>• Siltation | |
| Population and consumption growth | • Increases pressures to dam and divert more water, to drain more wetlands, etc.<br>• Increases water pollution sources<br>• Acid rain and potential for climate change | |

Source : Adapted from Postel and Richter, 2003.

# 3 Restoring the Riparian Zone

## 3.1 Overview

This section outlines key considerations for the restoration of riparian zones as habitats and/or corridors for biodiversity, buffers to protect river water quality and considerations for tree planting and maintenance.

It is important to have a good understanding of the existing and historical physical and biological conditions of the site, so that rehabilitation methods employed are appropriate to meet the objectives. As such, it should be noted that a number of different site assessments may be required in order to address each key consideration below.

## 3.2 Key considerations for biodiversity

In order to restore the functions of riparian zones as wildlife habitats and corridors, the composition and macro structure (i.e. woody trees) must be returned to a state where the basic requirements for wildlife are met. The restored riparian zones must provide food, offer protection, allow for movement and consequently the opportunity for biological interactions[2] to take place. In general, there are seven key considerations for biodiversity:

### *i) Plant a variety of suitable species*

It is best to plant a range of species which can perform a variety of functions. Criteria for species selection include original habitat composition, requirements of targeted animal species, tolerance to physical conditions at the site (particularly the hydrological and soil conditions at various sections of the riparian zone) and other objectives of restoration.

### *ii) Ensure suitable vertical stratification*

Animals occupy different niches in terms of vertical levels, from the ground, up to the under storey and upper canopy layers. Having the right mix of vertical stratification is important as it creates a variety of space in which a range of species may utilise (**Figure 5**).

Drawing by Teh Yew Kiang

**Figure 5.** Vertical stratification in a natural forest.

### *iii) Ensure continuity of canopy cover*

Suitable spacing and density of trees is important to sustain a diverse range of wildlife. A key consideration for this would be to ensure continuous canopy cover (**Figure 6**). This is especially important for arboreal species such as orang-utans and gibbons, which seldom go down to the ground. A continuous canopy cover would allow these animals to move along the corridor.

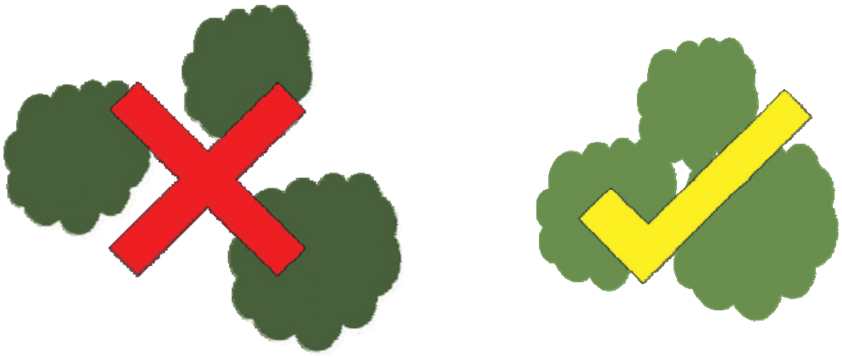


**Figure 6.** Continuity of canopy cover.

### *iv) Ensure availability of nesting material*

Plants that can be used as nesting material should be retained (if present) or planted so that animals can use the area as breeding or nesting grounds. As different animal species utilise different materials for nesting, care should be taken to ensure a variety of materials such as twigs and leaves are available. Old or dead trees which may provide nesting hollows should not be removed.

### *v) Retain dead branches, logs and leaf litter*

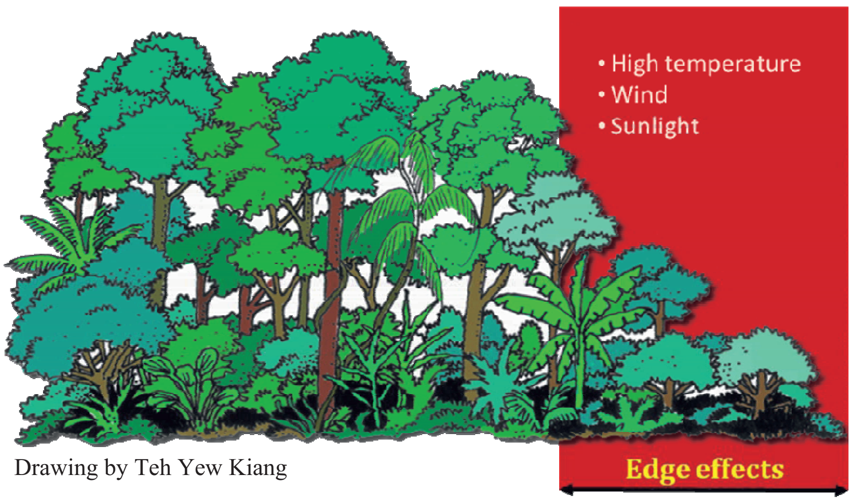
It is important that dead branches and logs on the ground are not removed, as they provide shelter, protection, nesting and breeding grounds for terrestrial and aquatic animals. The natural decomposition of these material, as well as leaf litter by ants and termites, are an important ecological process that contributes to the nutrient cycle.

### *vi) Ensure sufficient width*

The width required for riparian habitats and corridors is generally much greater than that required for water quality (minimum widths for biodiversity are within the region of 100–400m). While the rule of thumb is simply "the wider the better", two important aspects to consider are the animal species that the habitat and/or corridor is designed for and the impact of edge effects.

Large mammals such as elephants and tigers need to be given a wide berth, if just to minimise the risk human-wildlife conflicts.

"**Edge effects**" refer to the physical conditions at forest edges (e.g. increased exposure to wind, high temperatures and sunlight) which result in a high rate of tree mortality, degradation and loss of habitat variety, a shift in the species composition and structure of plant communities and consequently an overall loss of flora and fauna species. The perimeter-to-area ratio of the habitat increases when habitat sizes are reduced. This leads to a greater amount of area that suffers from 'edge effects'.




Drawing by Teh Yew Kiang

***vii) Keep landscape connectivity in mind***

**Term**

A "matrix" is a landscape of mixed land use not designated primarily for conservation of natural ecosystems, ecological processes and biodiversity.

It is important to consider the bigger picture, as rivers are dynamic systems. Even if only a limited section of the river is focused on in the short term, the activities and conditions upstream are likely to have a significant impact on the site. The layout (width, length and shape) and location of the site should be considered when planning riparian corridors for wildlife.

The patch-corridor matrix concept is useful to consider the structural connectivity between habitats in a landscape (**Figure 7**). Patches are essentially habitats which are in good condition and are able to support transitory wildlife populations moving between larger habitats (such as forest reserves or national parks). Corridors are strips of suitable habitats which allow for the movement of wildlife between patches.

The most preferable layout is for riparian corridors to be connected to larger patches of terrestrial forest habitats including Forest Reserves and other protected areas. Continuous buffers are more effective at moderating stream temperatures and providing movement corridors for animals. Therefore, the establishment of long continuous riparian habitats should be given higher priority over fragmented strips of greater width.

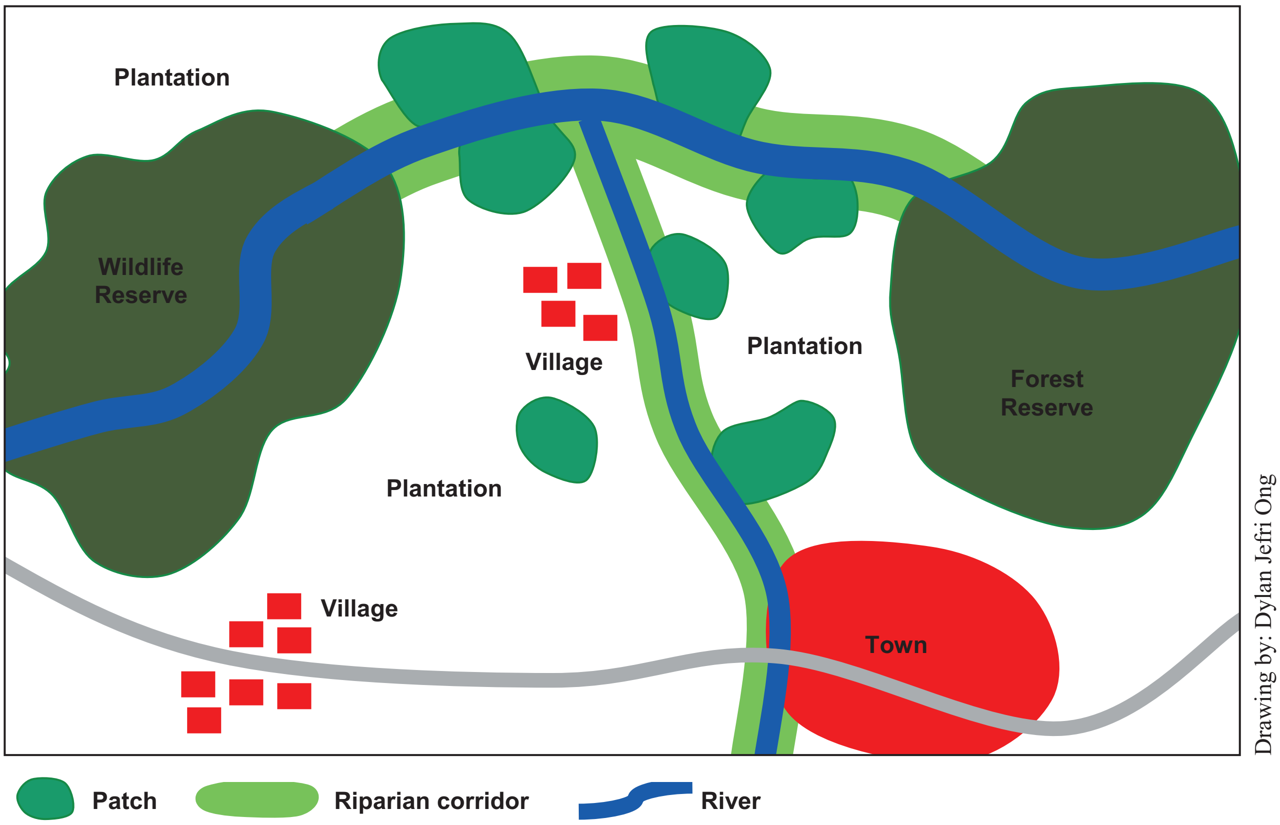



**Figure 7.** Example of a patch-corridor matrix in the riparian zone.

Suitable scales for this analysis are at the river basin level or habitat type level i.e. the entire length of the river flowing through a single habitat type (e.g. the entire length of original *Saraca* stream).

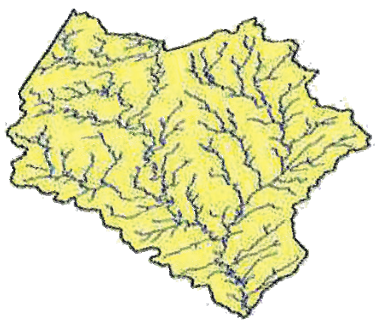


**Figure 8.** A river basin.

## Box 2. Kinabatangan - Corridor of Life (a case study)

***The project***

The lower 100km of the Kinabatangan river in Sabah meanders through low-lying ground to form the Kinabatangan floodplain, which is one of only two places on earth where ten primate species are found together, including the orang-utan, proboscis monkey and the Bornean gibbon. It is also home to over 250 bird, 50 mammal and 20 reptile species as well as 1,056 plant species. Since the 1950s, forests around the Kinabatangan has been converted for various economic activities, including logging activities and agriculture. Oil palm is the dominant commercial crop in the area today.

The Sabah state government declared the Lower Kinabatangan as Sabah's 'Gift to the Earth' in 1999 and in 2005, gazetted 26,000ha as the Kinabatangan Wildlife Sanctuary under the Sabah Wildlife Conservation Enactment 1997. WWF-Malaysia's Kinabatangan - Corridor of Life (KCol) project aims to establish a balance between the growing demands of private land development, the local community and the need to protect the unique wildlife along the riparian zone. The KCoL vision is as follows:

- A forest corridor along the Kinabatangan, connecting coastal mangrove swamps with the upland forests, where people, wildlife, nature-based tourism and local forest industries thrive and support each other.
- A floodplain that supports a thriving and diverse economy that offers opportunity and choice to local people and businesses.
- Good environmental management of the natural capital on which all partners depends upon.

Photo by Willian Unsworth

- A landscape in which agriculture, people and nature conservation is united by their common source of vitality – water.

***Working with partners***

A key factor contributing to the success of the project is engagement with all stakeholders, from government departments to NGOs, plantation companies and the local communities.

Photo by WWF-Malaysia

Oil palm plantations, including Asiatic Development, Borneo Samudera, and Pontian United Plantations have agreed to set aside land for reforestation, and some are even starting to venture into ecotourism. Local villagers have set up nurseries which supply saplings to the project, and are engaged in planting and maintenance work. Together with the growth of nature tourism, reforestation of KCol has provided locals with an excellent source of income as well as job and business opportunities.

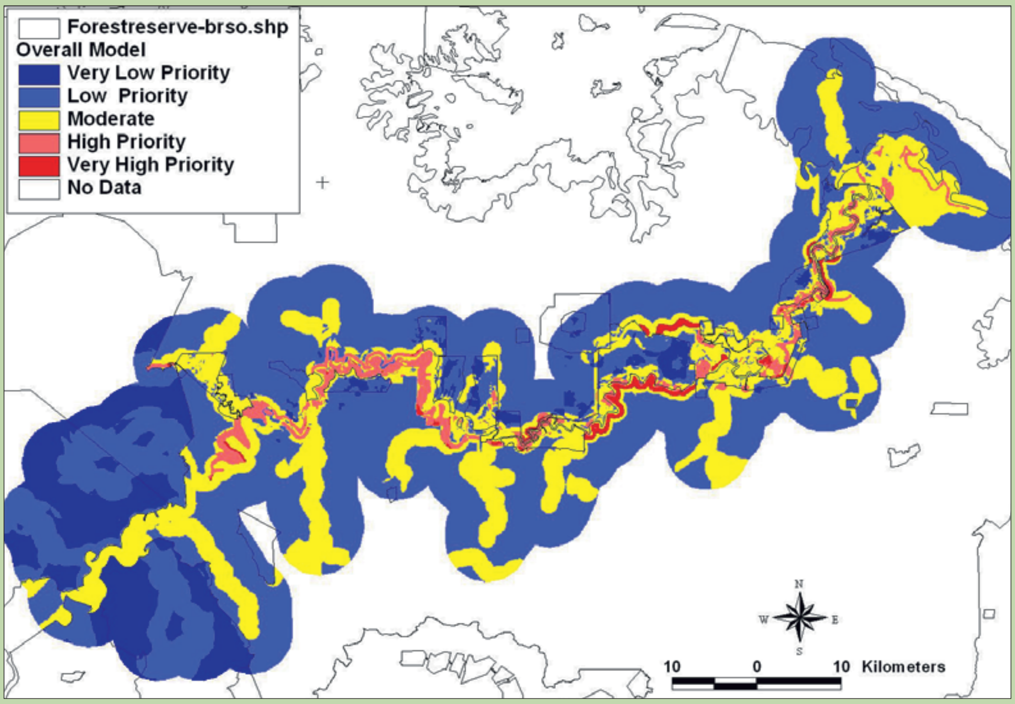
**Box 2. (cont.)**

***Forest restoration in KCoL***

The objective of the forest restoration component of KCoL is to achieve forest connectivity and enhance the quality of wildlife habitats. The long term goal is to establish contiguous forests, from coastal mangroves to the upland forests (encompassing an area of 150,677ha).The component includes nursery development and management, site selection and prioritisation, site preparation and tree planting as well as monitoring and maintenance.

A consultative process was used to prioritise areas for forest restoration. The first of a series of workshops was held in 2008, attended by representatives from Sabah Forestry Department, Sabah Wildlife Department, Universiti Malaya Sabah (UMS), Cardiff University and NGOs. The following criteria were used to identify priority areas, resulting in a prioritisation model (**Figure A**):

- Re-connect two forest fragments
- Restore natural riverine vegetation from the bank of every water course for ecological services
- Prevent extinction of orang-utan populations in lower Kinabatangan (by increasing gene flow)
- Improve wildlife habitat
- Enhance aesthetic value on areas highly visible along touristic routes
- Reduce human-wildlife conflict




Source: WWF-Malaysia

**Figure:** Prioritisation model for forest landscape restoration.

***Tree planting:***

Species native to Kinabatangan are planted, particularly those with fruits consumed by wildlife. So far, 17 different species have been planted, with a 5m x 5m spacing between saplings. However, the survival rate of planted saplings has been relatively low thus far, between 10-40%. The main causes of mortality are competition from weeds, inundation by seasonal floodwaters and trampling by elephants. The following actions have been taken to improve survival rates:

- Intensify weeding – monthly weeding in the first year, then once in three months in consecutive years.
- Plant taller saplings – only saplings over 1m high are planted to ensure they survive seasonal flooding.
- Plant at least three months before annual flooding season.
- Avoid planting on known elephant pathways.
- Erect temporary fencing around saplings.

## 3.3 Key considerations for water quality improvement

The maintenance of a vegetated riparian buffer is an important practice to minimise the amount of non-point source pollutants entering rivers, especially within plantations and farms. Through the interaction of vegetation, soil and hydrology, riparian forest buffers influence water quality as pollutants may be taken up into plant tissues, adsorbed onto soil particles, or modified by soil organisms[3].

It should be noted that a combination of practices, including proper application of fertilisers and pesticides or the introduction of measures to reduce stormwater runoff and soil erosion, is required to effectively reduce non-point source pollutants.

Four factors which determine the effectiveness of riparian buffers in filtering pollutants are hydrology[4], soil[5], vegetation and width. Of these, vegetation selection and width are controllable variables:

***i) Plant appropriate vegetation types***

Riparian vegetation influences water quality through the following means:

- By creating roughness along the surface of the ground. Vegetation decreases water velocity and allows time for water to infiltrate the soil and for sediments to drop out (Lowrance et al., 1995).
- By loosening the soil, thus allowing for increased infiltration of runoff.
- By maintaining high levels of organic carbon in the soil, which fuels denitrification and other biochemical processes.
- By adsorbing nutrients and other pollutants from soil water into plant tissues (Hupp et al., 1993).
- By supplying carbon needed to fuel microbial processes in the soil.

Different vegetation types (grass, shrubs and trees) have varying degrees of effectiveness in terms of their functions (**Table 3**). Utilising a combination of trees and shrubs is the most effective way to remove most pollutants. Non-native grass may be utilised in urban areas where sediment runoff is an issue, or where landscaping is an additional objective.

**Table 3.** Functions and effectiveness of plant types.

| Functions | Effectiveness | | |
|---|---|---|---|
| | Grass | Shrub | Tree |
| Stabilise riverbank erosion | Medium | High | Medium |
| Prevent bank failures | Low | Medium | High |
| Trap sediment | High | Medium | Low |
| Filter sediment-bound nutrients, pesticides and microbes | High | Low | Low |
| Filter soluble nutrients, pesticides and microbes | Medium | Low | Medium |

Source: Adopted from Fisher and Fischenich, 2000.

***ii) Ensure sufficient width***

Width is the most important controllable variable for the effectiveness of riparian buffers in filtering pollutants. Topography, hydrology and geology have implications on appropriate buffer widths. In order to be effective, plants must either have access to high water tables or sufficient unsaturated flow. Also, plants will not remove pollutants from water which is moving too rapidly such as on steep slopes or in defined channels.

Decisions on buffer widths are almost always a compromise between environmental goals and social or economic objectives, e.g. the value of water resources versus the value of adjacent land and plantations.

## 3.4 Species selection and layout

Based on the objectives and key considerations, the next question is what to plant (species selection) and where to plant (layout). A model design for the establishment of riparian zones for biodiversity and water quality improvement is given in **Appendix 1**.

There are two modes of habitat establishment:

- **Natural regeneration** – allowing nature to take its course with minimal human intervention. This method is suitable for areas where the riparian vegetation is recovering naturally through secondary growth. Such areas may have secondary tree species that provide ready cover, habitat and food source. Enrichment planting and silviculture[6] may be required in these areas.
- **Replanting** – the establishment of a new plant assemblage. This is required in areas that have little or no vegetation. Although more labour intensive and expensive than natural regeneration, it allows for greater control of the plant species composition.

A list of native trees, palms and shrubs suitable for planting in riparian zones is provided in **Appendix 2** together with a brief description of each species. This includes natural habitats, distribution, appropriate planting zones, planting radius and socio-economic use[7]. Some rivers may have endemic species. In such cases, propagation of these species would be extremely important in terms of plant conservation.

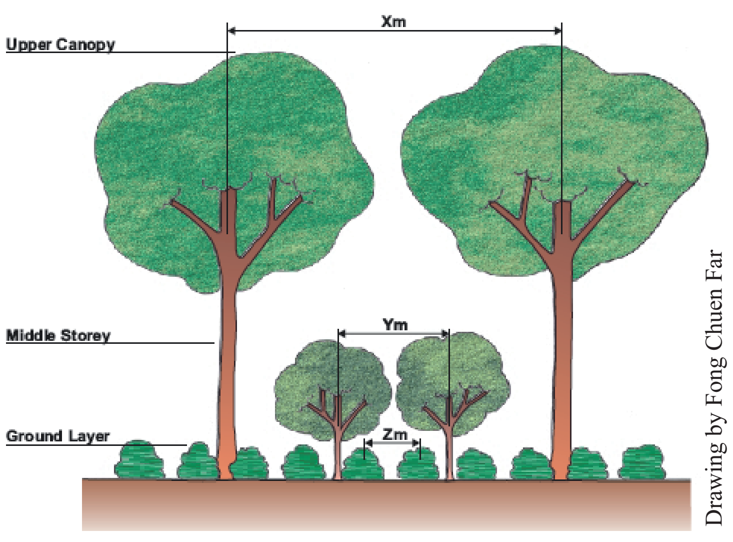



**Figure 9.** Spacing for different levels of the forest canopy.

In urban areas where the micro-climate is not conducive to the survival of native forest species, hardy coastal species commonly used in urban landscaping may be used. These include *Jemeriang Laut* (*Peltophorum pterocarpum*), *Bungor* (*Lagerstroemia speciosa*), *Jambu Laut* (*Eugenia grandis*), *Ketapang* (*Terminalia catappa*), *Bintangor Laut* (*Calophyllum inophyllum*) and *Mempari* (*Pongamia pinnata*).

To create a mixed stand of diverse tree species that mimics the complexity of a natural forest (**Figure 5**), traditional agroforestry layouts of rows or contour strips should not be used. Instead, different species should be planted in random order, taking into account the optimal spacing required to ensure continuity of the canopy cover (**Figure 9**).

## 3.5 Planting and maintenance

A tree that is properly planted will require less maintenance and have a higher chance of survival. Thus, the following are important considerations:

**i) *Seedlings and saplings***

Seedlings and saplings may be obtained from nurseries specialising in forest species. Alternatively, seeds, seedlings and saplings may be obtained from adjacent riparian areas. This method, which requires more time and resources, may involve seed collection and germination, branch cuttings with root inducement (for fast growing species) or saplings dug out from under the mother tree.

In any case, it is recommended that the seedlings are sown in poly bags in nurseries until they reach sufficient height (at least 1.5m) to minimise the risk of being overgrown by weeds or being eaten by herbivores.

***ii) Site preparation***

Earthworks which may be required to increase bank or slope stability around the planting site are covered in MASMA (DID, 2000). However, soft engineering methods should be used whenever possible. For example, coir logs made from coconut fibre can help in slope stabilisation and at the same time enhance plant growth and microbial activity.

***iii) Planting***

Saplings should be hardened for at least two weeks prior to planting in order to acclimatise them to stressful conditions such as minimal watering and increased exposure to sunlight. Weaker saplings should be disposed off before planting.

The diameter of the planting hole should be three times the diameter of the polybag and the height equal to the height of the polybag (**Figure 10**). Branches and leaves should be pruned and kept to a minimal (25% of actual leaf or branching contents) just before planting to reduce transpiration.

It is often necessary to protect saplings from animals, including birds, tree shrews and rats. Larger trees can tolerate far more leaf damage than newly planted seedlings, provided there is no severe damage to the new leaf bud. Tree guards may be installed, although they are a relatively expensive and labour intensive option. Different materials such as wire mesh and plastic may be used; most are supported by three stakes placed in a triangle around the sapling. However, wind resistant guards do not encourage strong root systems. It is important to remove the guards once the saplings have become well established (about after a year) so that they do not restrict further growth.

***iv) Maintenance***

Intensive maintenance, including watering, should be carried out within the first three months after planting, or at least until the saplings start to grow new leaves. This is also the time when fertilisers need to be applied. Periodical maintenance, which includes weeding and treatment for insect pests should then be carried out every six months.

The proliferation of woody and non-woody weeds in the tropical climate is the main threat to the survival of saplings. While the best solution is to plant tall saplings, weed control should be carried out periodically, especially in the first few years. Although labour intensive, the best method is by manual weeding. The use of herbicides should be prevented or at least minimised, as the chemicals may pollute the river.

Applying mulch around the saplings suppresses weed growth and at the same time reduces soil compaction and conserves moisture. However, excessive mulching should be avoided as this may deprive roots of oxygen, increase risk of fungal and bacterial infections due to constant moisture around the trunk and excessive heat from decomposition of the mulch can kill trunk tissue.

Saplings should be periodically inspected for signs of insect infestation or disease. Thinning and pruning may reduce attack in some circumstances, especially if trees are attacked by caterpillars. The presence of natural predators of insects will often effectively control their populations.

Repeated chemical spraying is expensive, polluting and can result in increased populations of some pests. Broad action insecticides that are sprayed repeatedly create a situation in which there is intense selection pressure for resistant individuals. Insects that survive intense spraying will produce offspring that will also survive. Judicious use of chemical insecticides, combined with methods that encourage natural control, will offset the expansion of pesticide-resistant insects.

Deciding which insect control method to use is not straightforward and can require detailed knowledge of the insects' biology. Accurate identification is very important; similar-looking species may require different control methods.

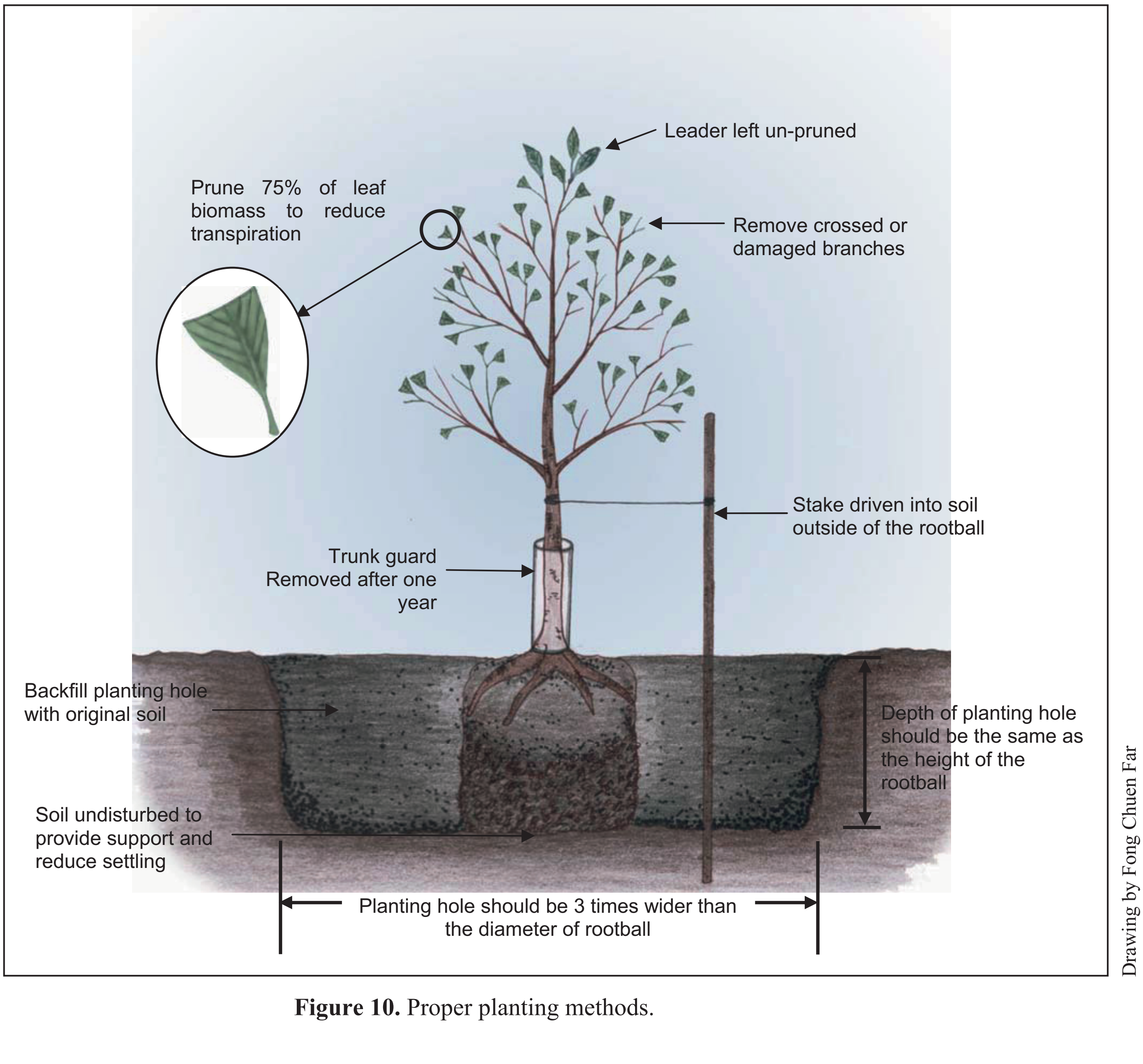



**Figure 10.** Proper planting methods.

# 4 Legal Framework

## 4.1 Overview

The Federal Constitution (9th Schedule, Item 6 of the State List) provides State Authorities in Peninsular Malaysia with absolute ownership of all land within the boundaries of its state. This includes all rivers, streams and watercourses, although rivers shared by more than one state fall under Item 11b of the Federal list. Similar powers are provided to the Sarawak State Authority under the Sarawak Land Code (Cap 81) and the Sabah State Authority under Section 26 (1) of the Land Ordinance Sabah (Cap 68).

Various state and federal agencies are involved in the control and management of rivers, each having specific responsibilities and legislative backing (**Table 4**). It is therefore important that an integrated and coordinated effort be adopted in the management of rivers and river basins.

**Table 4.** Key legislation and state agencies related to river management.

| State | Legislation | State Agencies |
|---|---|---|
| Federal Territory of Kuala Lumpur | • Waters Act 1920 (Revised 1989) | • DID Federal Territory of KL |
| Johor | • Enactment No. 66 (Johor 1921) | • DID Johor |
| Kedah | • Kedah Water Resources Enactment 2007 | • DID Kedah |
| Kelantan | • Enactment No. 18 of 1935 | • DID Kelantan |
| Melaka | • Waters Act 1920 (Revised 1989) | • DID Melaka<br>• Melaka River and Coastal Development Corporation |
| N. Sembilan | • Waters Act 1920 (Revised 1989) | • DID N. Sembilan |
| Pahang | • Pahang Water Resources Enactment 2007 | • DID Pahang |
| Perak | • Waters Act 1920 (Revised 1989) | • DID Perak |
| Pulau Pinang | • Waters Act 1920 (Revised 1989) | • DID P. Pinang |
| Perlis | • Enactment No.9 of 1357H (Perlis) | • DID Perlis |
| Sabah | • Sabah Water Resources Enactment 1998 | • DID Sabah<br>• Sabah Water Resources Department |
| Sarawak | • Natural Resources and Environment Ordinance 1993<br>• Sarawak Rivers Ordinance, 1993 | • DID Sarawak<br>• Natural Resources and Environment Board (NREB)<br>• Sarawak Rivers Board |
| Selangor | • Selangor Waters Management Authority Enactment No. 2 of 1999 | • DID Selangor<br>• Selangor Water Management Authority |
| Terengganu | • Enactment No. 2 of 1357H (Terengganu) | • DID Terengganu<br>• Terengganu Riverine and Coastal Agency |

Some key agencies are:

***Department of Irrigation and Drainage (DID)***

DID's role, which includes river basin management, flood management, agriculture drainage and coastal zone management, is provided for through the Ministerial Functions Act 1969 (Revised 2008).

***Local authorities***

The Local Government Act (1976) provides local authorities in Peninsular Malaysia with various powers. These include:

- Section 69, 70 and 71: Powers to recover expenses incurred in carrying out any work as a result of any person who commits a nuisance or deposits any filth in or upon the bank of any stream, channel, public drain or other watercourses.
- Section 73(a): Powers to make, amend or revoke by-laws to keep public places (including rivers) free from filth.
- Section 101(ee): Power to divert, strengthen, define and canalise the course of any stream, channel or watercourse subject to the consent of the appropriate authorities.

Local Authorities in Sabah and Sarawak are empowered with similar Acts.

The Streets, Drainage and Building Act 1974 (1994) provides Local Authorities in Peninsular Malaysia with further powers pertaining to the management of drains and water courses.

***Department of Town and Country Planning***

The Department of Town and Country Planning of Peninsular Malaysia is empowered to prepare statutory spatial plans, i.e. Structure Plans and Local Plans under Section 8 of the Town and Country Planning Act 1976. Plans for river reserves, river frontage development and floods levels etc., may be incorporated into the plans.

***Forestry Department***

The Forestry Department of Peninsular Malaysia, Sabah Forestry and Sarawak Forestry Corporation play a key role in enforcing their respective legislation and subsidiary regulations. The protection of water courses and water resources is an integral part of sustainable forest management. This includes classification and conservation of catchment forests, and ensuring that mitigation measures are implemented to minimise sedimentation from logging activities, especially in the construction of logging roads and skid trails.

## 4.2 Establishment of river reserves

In Peninsular Malaysia, river reserves are normally established through Section 62 of the National Land Code (1965), which gives the State Authority power to reserve state land for any public purpose. In August 2008, the National Water Resources Council agreed that state governments are to gazette river reserves.

The standard practice is for the NRE Minister to designate the Director of the Drainage and Irrigation Department (DID) as the officer having control of the river reserve, in order to enable the DID to manage the reserve. In addition, the Land Acquisition Act 1960 may be used to acquire private land in the river reserves.

The Guidelines for Rivers and River Reserves produced by DID specify widths of river reserves to a maximum of 50m, based on the width of the river (**Table 5**). However, it should be noted that the purpose of the guidelines is mainly for bank stabilisation; riparian zones as biodiversity habitats/corridors or water quality improvement require greater widths in general.

**Table 5.** Guidelines for width of river reserves.

| River width (m) | Width of river reserve (m) |
|---|---|
| >40 | 50 |
| 20 – 40 | 40 |
| 10 – 20 | 20 |
| 5 – 10 | 10 |
| <5 | 5 |

Source: DID, 2001.

In Sabah, the establishment of river reserves is provided for under Section 40 of the Sabah Water Resources Enactment 1998, which states that river reserves "*are to be established on land which is within 20 metres of the top of the bank of every river, including its estuary, where the channel is not less than three metres in width*". River reserves may also be established along channels less than three metres wide, upon the recommendation of the Sabah Water Resources Council. The purpose of the establishment of river reserves under Section 40 is for "*protecting the volume or flow of water in water bodies and preventing the degradation of the quality of water resources and damage to the aquatic environment in water bodies*".

From a legal and/or management perspective, the width of riparian zones may either be fixed or variable. Fixed-width zones are easier to gazette, enforce and administer, but often fail to provide for many ecological functions. Variable-width zones can be designed to carry out specific functions at various sections, taking into account the site-specific conditions and requirements along the length of the strip.

In addition to the more general river management enactments, other legislation (where available) has also been used to establish river reserves specifically for the purpose of protecting important wildlife habitats in the riparian zone. Examples include:

***Protection of firefly habitats***

The Selangor state government, through the Selangor Waters Management Authority Enactment 1999 (Government of Selangor Gazette, 2 July 2009). gazetted a river reserve in July 2009 to protect the firefly habitat along the banks of the Selangor river at Kampung Kuantan. The reserve ranges from 150m to 400m from the left and right bank of Sungai Selangor, and 20km to the upstream and 20km downstream from the Kg. Kuantan firefly jetty.

***Protection of terrapin habitats***

The Kedah state government gazetted two riparian stretches at Bukit Pinang and Sidam Kanan as sanctuaries in 1977, under the Kedah River Terrapin Enactment 1972. In the same year, the Bukit Paloh Terrapin Reserve was gazetted along a riparian stretch in Terengganu, under the state Turtles Enactment 1951 (WWF-Malaysia, 2008).

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# Annex 1

## Model riparian zone design

The following three-tiered buffer system has been adapted from the system developed by the USDA Forest Service (Welsch, 1991), which is one of the most widely used buffer planning models. The model, which takes into account biodiversity and water quality considerations, incorporates a zone specifically for in-stream aquatic habitat protection (Tier 1), and an optional zone specifically for filtering of sediments in surface runoff (Tier 3).

| Tier | Minimum width (m) | Main objectives | Vegetation | Management | Width considerations |
|---|---|---|---|---|---|
| **1** | 10 | 1. Protect in-stream aquatic habitat.<br>2. Bank stabilisation.<br>3. Habitat and corridor for terrestrial biodiversity. | Trees and shrubs with tolerance to periodical inundation. | Should remain undisturbed; tree removal is not permitted. Soft engineering methods such as coir logs may be used to strengthen the river bank. | - Width should be increased if the river bank is actively eroding.<br>- Width should be increased if the area receiving periodical inundation is wider than 10m. |
| **2** | 100 | 1. Habitat and corridor for biodiversity.<br>2. Uptake of nutrients from groundwater. | Ranging from trees and shrubs with tolerance to occasional inundation to dryland species. May include species with economic value in the form of Non-timber Forest Products (NTFP), e.g. fruits, bark, roots that can be utilised as food or fibre, etc. | Harvesting of NTFP without the use of heavy machinery is permitted. | - Width should be increased if the corridor is designed to cater for large mammals such as elephants or tigers. |
| **3*** | 10 | 1. Facilitate sediment filtering.<br>2. Convert surface runoff to uniform, shallow, sheet flow. | *Lalang* (*imperata cylindrica*), grass or other shrubs that provide groundcover. | May be utilised for livestock grazing. | - Width should be increased if there is a high amount of sediments or nitrates in the surface runoff.<br>- Width should be increased for steep slopes or deep groundwater flow. |

*** Note:** *Zone 3 is required only if there is a high amount of sedimentation from the adjacent land use, e.g. construction sites.*

# Annex 2

## Checklist of native plants suitable for planting in the riparian zone

| SPECIES DATA | | | | PLANTING DATA | | | | |
|---|---|---|---|---|---|---|---|---|
| **Species; [Family]; (Local name)** | **Habit** | **Habitat** | **Distribution** | **Type of river habitats for planting** | **Planting zones near river banks** | **Maximun height/ forest cover** | **Planting radius/ distance** | **Socio-economic/ Ecological benefits** |
| *Acer laurinum* Hassk.; [Aceraceae]; (Medang) | Tree to 30m tall | Peat swamp and lower montane forests | Kl, Ph, Sl, Jh; Sb & Sw | PS, MS | TF, UT | CA | 6m | FF, TS |
| *Acrostichum aureum* L.; [Pteridaceae]; (Piai Raja) | Terrestrial shrub to 4m tall | Mangroves and damp ground near the sea | PM: all coasts | MF | UT | GR | 0.8m | FB, FV, MD |
| *Acrostichum speciosum* Willd.; [Pteridaceae]; (Piai Raja) | Terrestrial shrub to 2m tall | Seaward parts of mangrove swamps | PM: all coasts | MF | UT | GR | 0.4m | FB |
| *Aegiceras corniculatum* (L.) Blanco; [Myrsinaceae]; (Kacang-kacang) | Small tree to 5m tall | Tidal mud and river estuaries | PM: widespread. | MF | TF | GR | 1m | FU, FV, PO |
| *Aglaia rubiginosa* (Hiern) Pannell; [Meliaceae]; (Bekak) | Tree to 35m tall | Lowland forest including peat swamps | Pk, Sl, Ml, Jh | FS, PS, RS | TF, UT | CA | 7m | FF, FS, TS |
| *Aglaia yzermannii* Boerl. & Koord.; [Meliaceae]; | Rheophytic tree to 5m tall | On riverbanks | Kl, Tg, Pk, Ph | NS | UB | GR | 1m | EC, FF |
| *Aglaonema nebulosum* N.E.Br.; [Araceae]; | Erect herb 10-60cm tall | Peat and freshwater swamp forest, also in the hills | PM: widespread | FS, PS, RS, NS, SS | LB, UB | GR | 0.1m | EC, FF, OR |
| *Alstonia angustifolia* Wall. *ex* A. DC.; [Apocynaceae]; (Pulai) | Small tree about 10m tall | Seasonal swamps in the lowlands | Pn, Ph, Sl, Ml, Jh; Sb & Sw | FS, RS | TF | MS | 2m | EC, EX, TS, WQ |
| *Alstonia pneumatophora* Back. *ex* L.G. den Berger; [Apocynaceae]; (Pulai basong) | Tree to 40m | Lowland swamps or hill forest | Pk, Ph, Sl, NS; Sb & Sw | FS, NS, SS | UT | CA | 8m | EC, EX, TS |
| *Aralia scandens* (Merr.) T.D. Ha; [Araliaceae]; | Scandent prickly shrub | Lowland and montane forest, often near streams | PK, Ph, Sl | NS, SS, MS | TF | GR | 1m | FF |
| *Aralidium pinnatifitidum* (Jungh. & de Vriese) Miq.; [Aralidiaceae]; | Shrub or small tree to 10m tall | Lowland and montane forest, often near streams | PM: throughout | NS, SS, MS | TF | GR | 2m | FF, MD, TS |
| *Archidendron kunstleri* (Prain) I.C. Nielsen; [Leguminosae]; (Jering) | Shrub or small tree to 15m tall | Often in swampy lowland forest | Pk, Ph, Jh; Sb & Sw | FS, RS | TF | MS | 3m | FF, TS |
| *Ardisia junghuhniana* Miq. var. *multiflora* B.C. Stone; [Myrsinaceae]; | Shrub or small tree to 10m tall | Lowland forest including swamps | Ph, Sl, Jh; Endemic to PM | FS, RS, NS | TF | GR | 2m | FF |
| *Arenga westerhoutii* Griff.; [Palmae]; (Kabong) | Feather palm to 10m or more tall | Gregarious in hillside forest | PM: widespread. | SS, MS | TF | MS | 2m | EC, FB, FF |

| SPECIES DATA | | | | PLANTING DATA | | | | |
|---|---|---|---|---|---|---|---|---|
| Species; [Family]; (Local name) | Habit | Habitat | Distribution | Type of river habitats for planting | Planting zones near river banks | Maximun height/ forest cover | Planting radius/ distance | Socio-economic/ Ecological benefits |
| *Artocarpus kemando* Miq.; [Moraceae]; (Terap) | Tree to 40m tall | Lowland swamp forest | Tg, Ph, Sl, Jh | FS, RS | UT | CA | 8m | EX, FB, FF, TS |
| *Artocarpus maingayi* King; [Moraceae]; (Terap) | Tree to 30m tall | Lowland swamp forest | PM: throughout | FS, RS | UT | CA | 6m | EX, FB, FF, TS |
| *Avicennia alba* Blume; [Avicenniaceae]; (Api-api hitam) | Tree to 21m tall | Muddy mangroves | PM: widespread; Sb & Sw. | MF | LB, UB | CA | 2m | EC, FF, WQ |
| *Avicennia officinalis* L.; [Avicenniaceae]; (Api-api ludat) | Tree to 18m tall | Mangrove, generally on landward fringe | PM: widespread; Sb & Sw | MF | LB, UB | MS | 1.5m | EC, FF, FU, WQ |
| *Barringtonia acutangula* (L.) Gaertn.; [Lecythidaceae]; (Putat nasi) | Shrub or small tree to 13m tall | Lowland forest near rivers | Kd, Tg, Pk, Ph, Jh; Sb & Sw | RS, NS, SS | TF | MS | 2m | FF, FV, MD, TS, SF |
| *Barringtonia conoidea* Griff.; [Lecythidaceae]; (Putat) | Shrub or small tree to 4m tall | Tidal estuaries | PM: common in the west coast. | MF, RS | LB, UB | GR | 0.8m | EC, FF, WQ |
| *Beilschmiedia pahangensis* Gamble; [Lauraceae]; | Tree to 15m tall | Lowland forest often near rivers | Kl, Pk, Ph; Endemic to PM | NS, SS | TF | MS | 3m | MD, TS |
| *Blumeodendron tokbrai* (Blume) J.J.Sm.; [Euphorbiaceae]; (Gaham badak) | Tree to 36m tall sometimes stilt-rooted | Lowland swamp and hill forests to 450m | Tg, Pk, Ph, Sl, Ns, Jh; Sb & Sw | FS, PS, NA, SS | TF, UT | CA | 7m | FF, TS |
| *Brackenridgea palustris* Bartell.; [Ochnaceae]; (Lidah mura) | Tree to 9m tall | Swampy lowland and montane forests | Kd, Pk, Ph, Sl, Ml, Jh; Sb & Sw | FS, MS | TF | GR | 2m | FF |
| *Brownlowia argentata* Kurz; [Tiliaceae]; (Dungun) | Shrub or small tree to 18m tall | Mangroves and tidal channels | PM: widespread; Sb & Sw | MF | UB | MS | 1.5m | EC, TS |
| *Bruguiera parviflora* (Roxb.) Wight & Arn. *ex* Griff.; [Rhizophoraceae]; (Berus) | Tree to 24m tall | Inner side of mangrove forests | PM: all coasts; Sb & Sw | MF | TF, UT | CA | 2m | EC, FU, WQ |
| *Buchanania arborescens* (Blume) Blume; [Anacardiaceae]; (Otak udang) | Tree to 27m tall | Common on riverbanks | PM: throughout; Sb & Sw | FS, RS | UB | CA | 5m | DT, MD, TS |
| *Calamus blumei* Becc.; [Palmae]; (Rotan) | Clustering rattan climbing to 15m tall | Swampy or wet forest to 800m | Pk, Ph, Sl, NS, Jh | FS, RS | UB | MS | 3m | FB, FF |
| *Calamus caesius* Blume; [Palmae]; (Rotan) | Clustering rattan to 100m long | Swampy and wet lowland forests | Pk, Ph, Sl, NS, Ml, Jh | FS, RS | UB, TF | GR | 2m | FB, FF, TS |
| *Calamus erinaceus* (Becc.) J. Dransf.; [Palmae]; (Rotan) | Robust thicket-forming rattan | Back mangrove | Tg, Pk, Ph, Sl, NS, Ml, Jh | MF | TF | GR | 2m | FB, FF |
| *Campnosperma auriculatum* (Blume) Hook. *f.*; [Anacardiaceae]; (Terentang daun besar) | Big tree to 33m tall | Lowland swamp and montane forests to 1600m | PM: widespread; Sb & Sw | FS, RS | TF, UT | CA | 6m | FF, TS |
| *Campnosperma squamatum* Ridl.; [Anacardiaceae]; (Terentang daun kecil) | Tree to 30m tall | Both swampy and dry lowland forest to 1200m | Kl, Tg, Ph, Sl, Jh; Sb & Sw | FS, RS, NS, SS, MS | TF, UT | CA | 6m | FF, TS |
| *Caryota maxima* Blume; [Palmae]; (Rabak | Solitary fishtail palm to | Montane forest at 1000-1500m | MR | MS | TF | CA | 6m | EC, FF |

| SPECIES DATA | | | | PLANTING DATA | | | | |
|---|---|---|---|---|---|---|---|---|
| Species; [Family]; (Local name) | Habit | Habitat | Distribution | Type of river habitats for planting | Planting zones near river banks | Maximun height/ forest cover | Planting radius/ distance | Socio-economic/ Ecological benefits |
| Gunung) | 30m tall | | | | | | | |
| *Cerbera odollam* Gaertn.; [Apocynaceae]; (Pong-pong) | Small tree | Mangrove and muddy coasts | PM: widespread; Sb & Sw | MF | TF | MS | 2m | EC, FU, MD, PO, VO |
| *Chionanthus ramiflorus* Roxb.; [Oleaceae]; | Tree to 17m tall | Riverine and swamp forest | PM: throughout; Sb & Sw | FS, RS, NS | TF, UT | MS | 3m | FF, TS |
| *Chisocheton amabilis* (Miq.) C. DC.; [Meliaceae]; | Tree to 17m tall | Peat swamp and riparian forest | Sl, Ph, Jh | PS, RS, NS | TF | MS | 3m | FF, TS |
| *Clerodendrum breviflorum* Ridl.; [Verbenaceae]; (Pepanggil) | Small ant-inhabited shrub | Swampy lowland forest | Pk, Sl, Jh; Endemic to PM | FS, RS | TF | GR | 1m | FF, OR |
| *Cordia dichotoma* G. Forst.; [Boraginaceae]; | Tree to 13m tall | Back mangrove | Ps, Kd, Pk, Ph, Sl, Ml, Jh | MF | TF | MS | 2.5m | FF, TS |
| *Costus globosus* Blume var. *ridleyi* (K. Schum.) Holttum; [Costaceae]; (Tepus) | Herb to more than 3m tall | Damp lowland forests | Pk, Ph, Sl, NS, Jh | NS, SS | UB | GR | 1m | MD, OR |
| *Cratoxylum arborescens* (Vahl) Blume var. *arborescens*; [Guttiferae]; (Geronggang) | Large tree to 42m tall | Lowland swamp forest and in the hills | Pn, Kl, Tg, Pk, Ph, Sl, NS, Ml, Jh; Sb & Sw | RS, NS, SS | UT | CA | 8m | DT, TS |
| *Crinum asiaticum* L.; [Amaryllidaceae]; | Herb to 2m tall | Riverine forest | PM: widespread. | FS, RS | UB | GR | 0.5m | EC, FB, OR, WQ |
| *Crudia wrayi* Prain; [Leguminosae]; | Tree to 6m tall | Lowland swamp forest | Kd, Pk, Jh; Sw | FS, RS | TF | GR | 1m | FF, TS |
| *Cryptocarya impressa* Miq.; [Lauraceae]; (Medang) | Tree to 33m tall | Lowland forests and swamps | NS, Ml, Jh | FS, RS, NS, SS | TF, UT | CA | 6m | FF, TS |
| *Cyathea glabra* (Blume) Copel.; [Cyatheaceae]; (Paku gajah) | Tree-fern to 4.5m tall | Damp forest to 1700m | Ps, Kd, KL, Tg, Pk, Ph, Sl, NS, Ml, Jh | NS, SS, MS | UB, TF | GR | 1m | EC, OR, WQ |
| *Cyathea trichodesma* (Scort.) Copel.; [Cyatheaceae]; (Paku gajah) | Tree-fern to 4.5m tall | Swampy lowland forest to 430m | Pk, Ph, Sl, NS | RS, NS, SS | TF | GR | 1m | EC, OR, WQ |
| *Cynometra ramiflora* L.; [Leguminosae]; (Katong laut) | Bushy-crowned tree to 25m tall | Riverbanks and swamps | PM: widespread; Sb & Sw | RS, NS, SS | TF | CA | 5m | EC, FF |
| *Cyperus iria* L.; [Cyperaceae]; | Herb to about 50cm tall | Open wet places to 700m; | PM: throughout. | FS, RS | LB | GR | 0.1m | EC, FP, WQ |
| *Dacryodes incurvata* (Engl.) H.J. Lam; [Burseraceae]; (Kedondong) | Tree to 30m tall | Lowland and hill forest including swamps | Kl, Tg, Pk, Ph, Sl, Jh; Sb & Sw | NS, SS | UT | CA | 5m | FF, TS |
| *Daemonorops sabut* Becc.; [Palmae]; (Rotan) | Clustering rattan to 20m or more tall | Freshwater swamp forest to 250m | Tg, Pk, Ph, NS, Jh | FS, RS, NS, SS | TF | GR | 1m | FB, FF, TS |
| *Dialium indum* L. var. *bursa* (de Wit) Rojo; [Leguminosae]; (Keranji paya) | Tree to 35m tall | Lowland swamp forest | PM: widespread; Sb & Sw | FS | UT | CA | 7m | FF, TS |
| *Dillenia indica* L.; [Dilleniaceae]; (Simpoh) | Tree to 20m tall | On stream banks; | Kl, Tg, Pk, Ph, Sl, Jh | NS, SS | UB | MS | 5m | EX, FF, TS |
| *Dipterocarpus oblongifolius* Blume; | Large tree | Banks of fast flowing rivers | PM: east of MR; Sb & Sw | NS | UB | CA | 8m | EC, FF, TS, WQ |

| SPECIES DATA | | | | PLANTING DATA | | | | |
|---|---|---|---|---|---|---|---|---|
| Species; [Family]; (Local name) | Habit | Habitat | Distribution | Type of river habitats for planting | Planting zones near river banks | Maximun height/ forest cover | Planting radius/ distance | Socio-economic/ Ecological benefits |
| [Dipterocarpaceae]; (Keruing neram) | | | | | | | | |
| *Dolichandrone spathacea* (L. *f.*) K.Schum.; [Bignoniaceae]; (Tui) | Tree to 24m tall | Mangroves and other muddy areas near the sea | PM: widespread; Sb & Sw | MF | UT | CA | 5m | FB, MD, TS |
| *Dracaena cantleyi* Baker; [Dracaenaceae]; | Shrub to 4m tall | Swamps and forest margins | PM: widespread | FS, NS | UB | GR | 1m | EC, OR |
| *Dracontomelon dao* (Blanco) Merr. & Rolfe; [Anacardiaceae]; | Big buttressed tree to 36m tall | Lowland forest, often near rivers | Kd, Kl, Tg, Pn, Pk, Ph, Sl, NS | NS, SS | UB | CA | 7m | FF, MD, TS |
| *Dryobalanops oblongifolia* Dyer ssp. *occidentalis* P.S. Ashton; [Dipterocarpaceae]; (Kapur paya) | Big tree | Swampy lowland forest | Pk northward; Sw | FS | TF, UT | CA | 8m | FF, TS |
| *Duabanga grandiflora* (Roxb. ex DC.) Walp.; [Lythraceae]; | Tree to 35m tall | Lowland and hills, often near river | NS northward. | NS, SS | TF, UT | CA | 7m | EC, FF, TS |
| *Dyera costulata* (Miq.) Hook. *f.*; [Apocynaceae]; (Jelutong) | Huge lactiferous tree to more than 60m tall | Lowland swamp forests | Kd, Kl, Tg, Pn, Pk, Ph, Sl, NS, Ml, Jh; Sb & Sw | FS, PS | TF | CA | 10m | EX, TS |
| *Dysoxylum angustifolium* King; [Meliaceae]; | Rheophytic tree to 9m tall | Banks of fast-flowing rivers | Kl, Tg, Ph; Endemic to PM | NS, SS | LB, UB | GR | 2m | FF, PO, TS |
| *Elaeocarpus griffithii* (Wight) A. Gray; [Elaeocarpaceae]; (Medang kelawar) | Tree to 7m tall | Lowland forest near rivers and swamps | Kd, Pk, Ph, Sl, Jh; Sb & Sw | FS, NS, SS | TF | GR | 1.5m | FF, TS |
| *Eleiodoxa conferta* (Griff.) Burret; [Palmae]; (Asam paya) | Stemless thicket-forming feather palm to 6m tall | Wet places in lowland forest | PM: throughout | FS | TF | GR | 2m | FB, FB, FF, MD |
| *Etlingera littoralis* (J. K"nig) Giseke; [Zingiberaceae]; (Tepus) | Herb 3-6m tall | Damp forest in the lowlands and hills | PM: throughout | NS, SS | UB, TF | GR | 0.5m | FF, OR, SF |
| *Etlingera punicea* (Roxb.) R.M. Sm.; [Zingiberaceae]; (Tepus) | Herb 2-4m high | Damp forest in the lowlands and hills | PM: throughout | NS, SS | UB, TF | GR | 0.5m | FF, OR, SF |
| *Excoecaria agallocha* L.; [Euphorbiaceae]; (Buta-buta) | Small tree to 15m tall | Mangrove swamps | PM: all coasts; Sb & Sw | MF | UB | MS | 2m | EC, MD, PO, TS, WQ |
| *Fagraea fragrans* Roxb.; [Loganiaceae]; (Tembusu) | Tree to 30m tall | Open swampy places | PM: throughout | FS | UT | CA | 6m | FF, OR, TS |
| *Fagraea ridleyi* King & Gamble; [Loganiaceae]; (Tembusu) | Scandent shrub or small tree | Along riverbanks | PM: scattered | NS | TF | GR | 2m | EC, FF, OR |
| *Ficus beccarii* King; [Moraceae]; (Ara Tanah) | Srubby earth-fig to 5m tall | Near rocky streams | Tg to Jh | NS, SS | LB | GR | 1m | EC, FF |
| *Ficus heterophylla* L. *f.*; [Moraceae]; (Ara) | Srub to 6m tall | Sandy river banks | NS northward | NS | UB | GR | 1m | EC, FF |
| *Ficus ischnopoda* Miq.; [Moraceae]; (Ara) | Shrub to 5m tall | In and near rocky streams | Central and North PM | NS | LB, UB | GR | 1m | EC, FF |

| SPECIES DATA | | | | PLANTING DATA | | | | |
|---|---|---|---|---|---|---|---|---|
| Species; [Family]; (Local name) | Habit | Habitat | Distribution | Type of river habitats for planting | Planting zones near river banks | Maximun height/ forest cover | Planting radius/ distance | Socio-economic/ Ecological benefits |
| *Ficus microcarpa* L. *f.*; [Moraceae]; (Jejawi) | Large tree with aerial roots | Swampy places | PM: widespread; Sb & Sw | FS, RS | UB, TF | CA | 15m | EC, EX, FF, MD, OR |
| *Ficus oligodon* Miq.; [Moraceae]; (Ara) | Tree to 12m tall | By lowland and mountain streams | north of PM | NS, SS, MS | UB, TF | MS | 2.5m | EC, FF |
| *Ficus pisocarpa* Blume; [Moraceae]; (Ara) | Tree to 18m tall | Lowland forest near streams | Pk, Ph, Sl, NS, Ml | RS, NS | UB | MS | 3.5m | EC, FF |
| *Ficus semicordata* Buch.-Ham. *ex* Sm.; [Moraceae]; (Ara tanah) | Earth-fig to 12m tall | Secondary forest often near streams | north of PM | RS, NS | UB | MS | 2.5m | FF, OR, PO |
| *Garcinia opaca* King var. *dumosa* Whitmore; [Guttiferae]; (Kandis) | Tee to 12m tall | Lowland forest and swamps | Pk, Ph, Sl, Jh; Endemic to PM | FS, NR, SS | TF | MS | 2.5m | FF |
| *Gardenia pterocalyx* Valeton; [Rubiaceae]; | Small tree to 5m tall | Lowland swamp and hill forest | Tg, Ph | RS, NS, SS | UB, TF | GR | 1m | EC, FF, OR |
| *Globba variabilis* Ridl. ssp. *variabilis*; [Zingiberaceae]; (Tepus) | Herb to 50m tall | Damp places in lowland and hill forest | Pk southward; Endemic to PM | NS, SS, MS | LB, UB | GR | 0.1m | MD, SF |
| *Glochidion perakense* (Mull.Arg.) Airy Shaw; [Euphorbiaceae]; | Shrub or small tree to 6m tall | Tidal freshwater reaches | PM: widespread | RS | UB | GR | 1m | EC, FF |
| *Gluta malayana* (Corner) Ding Hou; [Anacardiaceae]; (Rengas) | Tree to 45m tall | Lowland forest including swamps | Kd, Tg, Pk, Ph, Sl, Jh | FS, NS, SS | TF | CA | 9m | PO, TS |
| *Gluta pubescens* (Ridl.) Ding Hou; [Anacardiaceae]; (Rengas) | Tree to 40m tall | Lowland forest, including swamps, to 400m | Kl, Tg, Ph, NS, Ml, Jh | FS, NS, SS | TF | CA | 8m | PO, TS |
| *Gluta renghas* L.; [Anacardiaceae]; (Rengas) | Tree to 30m tall | Tidal freshwater reaches | Kd, Kl, Tg, Ph, Jh | FS, RS | UB | CA | 6m | EC, PO, TS, WQ |
| *Gluta velutina* Blume; [Anacardiaceae]; (Rengas) | Large shrub or stilt-rooted tree to 20m tall | Banks of tidal rivers | Kd, Pk, Ph, Sl, Jh | MF, RS | LB, UB | MS | 4m | EC, FV, PO, TS |
| *Gonystylus bancanus* (Miq.) Kurz; [Thymelaeaceae]; (Ramin melawis) | Tree to 27m tall | Peat swamp forest | Pk, Sl, Jh; Sb & Sw | PS | TF | CA | 5.5m | FF, MD, TS |
| *Guioa pleuropteris* (Blume) Radlk.; [Sapindaceae]; (Penyamok) | Tree to 10m tall | Riverine forest | PM: widespread; Sb & Sw | NS, SS | UB | GR | 2m | FF, MD, TS |
| *Gymnacranthera farquhariana* (Hook. *f.* & Thomson) Warb. var. *zippeliana* (Miq.) R.T.A. Schouten; [Myristicaceae]; (Pendarahan) | Tree to 30m tall | Lowland swamp forest | Pk, Ph, Sl, Jh | FS, PS | TF | CA | 6m | FF, TS |
| *Gynotroches axillaris* Blume; [Rhizophoraceae]; (Mata keli) | Tree to 36m tall | Lowland swamps, to mountains at 1400m | PM: throughout; Sb & Sw | FS, NS, SS, MS | TF, UT | CA | 7m | FF, MD, TS |
| *Hanguana malayana* (Jack) Merr.; [Hanguanaceae]; (Bakung) | Herb to 2m tall | Lowland swamps to mountains at 1500m | PM: widespread | FS, PS, RS, NS, SS, MS | LB, UB, TF, UT | GR | 0.4m | EC, FB, WQ |
| *Helicia attenuata* (Jack) Blume; [Proteaceae]; (Golang paya) | Shrub or small tree to 20m tall | Lowlands and mountains near streams | Ps, Kd, Kl, Tg, Pn, Pk, Ph, Sl, Jh; Sb & Sw | NS, SS, MS | TF | MS | 4m | EX |

| SPECIES DATA | | | | PLANTING DATA | | | | |
|---|---|---|---|---|---|---|---|---|
| Species; [Family]; (Local name) | Habit | Habitat | Distribution | Type of river habitats for planting | Planting zones near river banks | Maximun height/ forest cover | Planting radius/ distance | Socio-economic/ Ecological benefits |
| *Helicia robusta* (Roxb.) R.Br. *ex* Wall.; [Proteaceae]; (Medang keladi) | Small tree to 10m tall | Lowland and hill forest, mostly near streams | Kd, Kl, Tg, Ph, Sl, Ml, Jh; Sb & Sw | NS, SS | UB, TF | GR | 2m | FV, MD, PO, TS |
| *Heritiera littoralis* Dryand.; [Sterculiaceae]; (Dungun) | Small bushy tree to 15m tall | Mangrove swamps | PM: all coasts; Sb & Sw | MF | TF | MS | 2m | EC, TS |
| *Hibiscus floccosus* Mast.; [Malvaceae]; (Kangsar) | Tree to 20m tall | Lowland forests, often along rivers | Ml northward; Endemic to PM | RS, NS, SS | TF, UT | MS | 4m | FB, FF, TS |
| *Hibiscus tiliaceus* L.; [Malvaceae]; (Baru-baru) | Tree to 12m tall | Tidal freshwater reaches | PM: throughout; Sb & Sw | MR, RS | UB, TF | MS | 2.5m | EC, FB, FP, FV, MD, OR, TS |
| *Homalium foetidum* (Roxb.) Benth.; [Flacourtiaceae]; | Tree to 24m tall | Lowland forest often near rivers | Pn, Kl, Pk, Ml. | NS, SS | UB, TF | CA | 5m | EC, TS |
| *Hopea coriacea* Burck; [Dipterocarpaceae]; (Giam hantu) | Tall buttressed tree | Lowland forest, often near rivers | Kl, Tg, Ph; Sw | NS, SS | UB, TF | CA | 7m | EC, TS |
| *Ilex maingayi* Hook. *f.*; [Aquifoliaceae]; | Small to medium-sized tree | Peat swamp forest | South and west of PM; Endemic | PS | TF | MS | 4m | FF |
| *Intsia bijuga* (Colebr.) Kuntze; [Leguminosae]; (Merbau ipil) | Tree to 25m tall | Tidal reaches of rivers | PM: throughout; Sb & Sw | MF, RS | UB | CA | 5m | FF, MD, TS |
| *Ixora lobbii* King & Gamble var. *stenophylla* Corner; [Rubiaceae]; (Jejarum) | Shrub to 2m tall | Rocky stream banks in lowland forest | PM: widespread. | NS, SS | UB | GR | 0.4m | FF, MD, OR |
| *Jackiopsis ornata* (Wall.) Ridsdale; [Rubiaceae]; (Medang gambut) | Tree to 35m tall | Lowland swamps or near rivers | PM: widespread; Sb & Sw | FS, NS, SS | UB, TF | CA | 7m | TS |
| *Kailarsenia tentaculata* (Hook. *f.*) Tirveng.; [Rubiaceae]; | Shrub to 1.5m tall | Riverbanks | PM: widespread | NS, SS | UB | GR | 0.3m | FF, OR |
| *Knema curtisii* (King) Warb. var. *paludosa* J. Sinclair; [Myristicaceae]; (Pendarahan) | Tree to 10m tall | Freshwater swamp forest | Pn, Kl, Tg, Pk, Ph, Sl, NS, Ml, Jh; Sb & Sw | FS | TF | GR | 2m | FF, TS |
| *Lagerstroemia speciosa* (L.) Pers.; [Lythraceae]; (Bungor) | Tree to 15m tall | Open country near rivers | NS northward; Sb & Sw | NS, SS | UB, TF | MS | 3m | DT, EC, EX, FF, MD, OR, TS |
| *Lasianthus filiformis* King & Gamble var. *bracteatus* King & Gamble; [Rubiaceae]; | Shrub to 1m tall | Lowland and hill forest, including swamps | Tg, Pk, Ph, Sl, NS; Endemic to PM | FS, RS, NS, SS | TF | GR | 0.2m | FF, OR |
| *Licuala spinosa* Wurmb; [Palmae]; (Palas) | Clumping fan palm to 6m tall | Open country near rivers | PM: throughout | FS, RS, NS | UB, TF | GR | 1m | FB, FF, OR |
| *Lophopetalum multinervium* Ridl.; [Celastraceae]; (Perupok) | Tree to 35m tall often with short columnar pneumatophores | Peat swamp forest | Pk, Ph, Jh; Sb & Sw | PS | UB | CA | 7m | EC, FF, TS |

| SPECIES DATA | | | | PLANTING DATA | | | | |
|---|---|---|---|---|---|---|---|---|
| **Species; [Family]; (Local name)** | **Habit** | **Habitat** | **Distribution** | **Type of river habitats for planting** | **Planting zones near river banks** | **Maximun height/ forest cover** | **Planting radius/ distance** | **Socio-economic/ Ecological benefits** |
| *Macaranga diepenhorstii* Mull.Arg.; [Euphorbiaceae]; (Mahang) | Tree to 24m tall | Along rivers in primary forest | Kl, Tg, Pk, Ph, Sl, Ml | RS, NS, SS | UB, TF | CA | 5m | EC, FF |
| *Macaranga motleyana* (Mull.Arg.) Mull.Arg. ssp. *griffithiana* (Mull.Arg.) Whitmore; [Euphorbiaceae]; (Mahang bulan) | Small bushy tree | Freshwater swamp forest | PM: throughout; Sb & Sw | FS, RS | UB, TF | GR | 2m | EC, FF |
| *Macaranga pruinosa* (Miq.) Mull.Arg.; [Euphorbiaceae]; | Tree to 15m tall | Freshwater swamp forest | PM: throughout; Sb & Sw | FS, PS | TF | MS | 3m | EC, FF |
| *Macaranga puncticulata* Gage; [Euphorbiaceae]; (Mahang) | Tree to 15m tall | Freshwater swamp forest | Pk, Sl, Ml, Jh | FS, RS | TF | MS | 3m | EC, FF |
| *Madhuca motleyana* (de Vriese) J.F. Macbr.; [Sapotaceae]; (Nyatoh ketiau) | Tree to 35m tall | Lowland forest and swamps | PM: widespread; Sb & Sw | FS, NA, SS | TF | CA | 7m | EX, FF, TS |
| *Mallotus floribundus* (Blume) Mull.Arg.; [Euphorbiaceae]; (Balik angina) | Small tree | Common along river banks | Ph northward, also Jh; Sb & Sw | RS, NS | UB, TF | GR | 2m | FF, MD, TS |
| *Mapania squamata* (Kurz) C.B. Clarke; [Cyperaceae]; | Large tufted herb | Damp lowland and hill forest to 1500m | Sl, NS, Jh | NS, SS, MS | TF, UT | GR | 0.2m | EC, OR |
| *Mapania tenuiscapa* C.B. Clarke; [Cyperaceae]; | Large tufted herb | Damp lowland forest | Kd, Pk, Ph, NS, Ml, Jh | NS, SS | TF | GR | 0.2m | EC, OR |
| *Melaleuca cajuputi* Powell; [Myrtaceae]; (Gelam) | Shrub or tree to 24m tall | Freshwater swamp forest | PM: widespread | FS | TF, UT | CA | 5m | BV, EC, EO, FB, FU, MD, OR, TS |
| *Merope angulata* (Willd.) Swingle; [Rutaceae]; | Spiny shrub or small tree | Mangrove swamps | Pk, NS, Ml, Sp | MF | TF, UT | GR | 2m | EO, FF, MD |
| *Mesua ferruginea* (Pierre) Kosterm.; [Guttiferae]; (Penaga) | Small tree | By lowland rivers | Kl, Ph, Jh | RS, NS, SS | UB, TF | GR | 2m | FF, TS |
| *Microcos antidesmifolia* (King) Burret; [Tiliaceae]; (Bunsi) | Tree to 24m tall | Lowland forest, often near rivers | Kl, Tg, Pk, Ph, Sl, Jh | RS, NS, SS | UB, TF | CA | 5m | FB, FF, TS |
| *Mussaendopsis beccariana* Baill.; [Rubiaceae]; (Merlimau penyabong) | Tree to 35m tall | Freshwater swamp forest | Pk, Ph, Sl, NS, Ml, Jh; Sb & Sw | FS | TF | CA | 7m | FF, TS |
| *Myristica elliptica* Wall. *Ex* Hook. *f.* & Thomson; [Myristicaceae]; (Pendarahan) | Tree to 30m tall | Freshwater swamp forest | PM: throughout | FS | TF | CA | 6m | FF, MD, TS |
| *Myristica lowiana* King; [Myristicaceae]; (Pendarahan) | Stilt-rooted tree to 25m tall | Peat swamp forest | PM: scattered | PS | TF | CA | 5m | FF, TS |
| *Neesia malayana* Bakh.; [Bombacaceae]; (Bengang) | Tree to 25m tall | Freshwater swamp forest | PM: Tg, Ph, Jh; Sb & Sw | FS, RS | TF, UT | CA | 5m | FF, TS |
| *Neolamarckia cadamba* (Roxb.) Bosser; | Pagoda tree to 40m tall | Lowland and hill forest, often | Jh northwards | NS, SS | Ub, TF | CA | 8m | FB, FF, MD, OR, |

| SPECIES DATA | | | | PLANTING DATA | | | | |
|---|---|---|---|---|---|---|---|---|
| Species; [Family]; (Local name) | Habit | Habitat | Distribution | Type of river habitats for planting | Planting zones near river banks | Maximun height/ forest cover | Planting radius/ distance | Socio-economic/ Ecological benefits |
| [Rubiaceae]; | | near rivers | | | | | | TS |
| *Neonauclea pallida* (Reinw. *ex* Havil.) Bakh. *f.* ssp. *malaccensis* (Gand.) Ridsdale; [Rubiaceae]; (Mengkal) | Shrub or small tree to 12m tall | Lowland to montane forest, often near rivers | PM: widespread | NS, SS, MS | UB, TF | MS | 2.5m | EC, FF |
| *Neoscortechinia philippinensis* (Merr.) Welzen; [Euphorbiaceae]; (Beki) | Small tree | Lowland and hill forest to 700m, often in swamps | Kd, Tg, Sl, Jh; Sb & Sw | FS, RS, NS, SS | UB, TF | GR | 2m | EC, TS |
| *Nephelium lappaceum* L. var. *pallens* (Hiern) Leenh.; [Sapindaceae]; (Rambutan) | Tree to 25m tall | Swampy lowland forest to 400m | PM: scattered; Sb & Sw | FS, RS, NS, SS | TF | CA | 5m | DT, FF, MD, TS, VO |
| *Nephelium laurinum* Blume; [Sapindaceae]; | Tree to 20m tall | Lowland forest, often near streams | PM: widespread. | NS, SS | UB, TF | MS | 4m | FF, TS |
| *Nephelium ramboutan-ake* (Labill.) Leenh.; [Sapindaceae]; (Pulasan) | Tree to 35m tall | Lowland forest, often near rivers | Pn, Kl, Tg, Pk, Ph, Sl, Ml; Sb & Sw | NS, SS | UB, TF | CA | 7m | BV, FF, MD, TS, VO |
| *Norrisia maior* Soler.; [Loganiaceae]; (Sarapak paya) | Tree to 24m tall | Lowland forest, often near rivers | Sl southward; Sb & Sw | NS, SS | UB, TF | CA | 5m | FF, TS |
| *Nypa fruticans* Wurmb; [Palmae]; (Nipah) | Rizomatous rosette feather palm to 6m tall | Gregarious in tidal reaches of estuaries | PM: throughout | MF | LB, UB | GR | 1m | BV, EC, FB, FF, FS, MD, WQ |
| *Oncosperma tigillarium* (Jack) Ridl.; [Palmae]; (Nibong) | 20m-tall spiny feather palm growing in many-stemmed clumps | Back mangrove | PM: throughout | MF, RS | UB, TF | MS | 4m | FF, FV, OR, TS |
| *Palaquium xanthochymum* (de Vriese) Pierre *ex* Burck; [Sapotaceae]; (Nyatoh babi) | Tee to 40m tall | Lowland swamp forest | Tg, Pk, Ph, Sl, Jh | FS, RS | UB, TF | CA | 8m | EX, FF, TS |
| *Pandanus affinis* Kurz; [Pandanaceae]; (Mengkuang) | Srub to 5m tall | Freshwater or brackish swamps | Tg, Ph, Sl, NS, Jh | MF, RS | UB | GR | 1m | EC, FB, FF, WQ |
| *Pandanus helicopus* Kurz; [Pandanaceae]; (Rasau) | Tall erect aquatic shrub | Freshwater swamps, usually standing in water | Sl, Ph, Jh | FS, RS | LB, UB | GR | 2m | EC, FB, FF, WQ |
| *Pandanus motleyanus* Solms; [Pandanaceae]; (Mengkuang) | Sender erect shrub to 5m tall | Near forest streams or in swampy forest | PM: scattered | FS, RS, NS | UB, TF | GR | 1m | FB, FF |
| *Pandanus yvanii* Solms; [Pandanaceae]; (Mengkuang) | Tall prickly shrub 5-6m tall | Common along water courses in shady forest | Pk, Ph, Sl, NS, Ml, Jh | NS, SS | UB | GR | 1m | FB, FF |
| *Parishia insignis* Hook. *f.*; [Anacardiaceae]; | Very tall tree reaching 60m | Lowlands to 300m, including swamps | Kd, Kl, Pn, Pk, Ph, Ml, Jh | FS, NS, SS | TF, UT | CA | 12m | FF, TS |
| *Pentaspadon velutinus* Hook. *f.*; [Anacardiaceae]; (Pelong) | Big tree to 48m tall | Lowland and hill forest, often by streams | Kl, Pk, Ph, Sl, NS, Ml | FS, NS, SS | UB, TF | CA | 9.5m | FF, TS |

| SPECIES DATA | | | | PLANTING DATA | | | | |
|---|---|---|---|---|---|---|---|---|
| **Species; [Family]; (Local name)** | **Habit** | **Habitat** | **Distribution** | **Type of river habitats for planting** | **Planting zones near river banks** | **Maximun height/ forest cover** | **Planting radius/ distance** | **Socio-economic/ Ecological benefits** |
| *Phoenix paludosa* Roxb.; [Palmae]; (Kurma) | Clumping feather palm to 6m tall | Inland edge of mangrove forests | Ps, Kd, Kl, Tg, Pn, Pk | MF | TF | GR | 1m | DT, FB, FF, FV, OR |
| *Pholidocarpus kingianus* (Becc.) Ridl.; [Palmae]; (Serdang) | Solitary fan palm to 25m tall | Lowland swamp forest | PM: widespread and endemic | FS | TF | CA | 5m | FF, TS |
| *Pholidocarpus macrocarpus* Becc.; [Palmae]; (Serdang) | Solitary fan palm to 15m tall | Lowland swamp forest | PM: widespread | FS | TF | MS | 3m | FF, TS |
| *Phragmites vallatoria* (Pluk. *ex* L.) Veldkamp; [Gramineae]; | Reed to 3m tall | Margins of rivers and lakes | Ps, Kd, Pn, Pk, Ph, Sl, NS, Ml, Jh | FS, RS | LB, UB | GR | 0.6m | EC, FB, FP, WQ |
| *Phyllanthus pulcher* Wall. *Ex* Mull.Arg.; [Euphorbiaceae]; | Shrub to 60cm tall | Open ground, often near rivers | PM: widespread | NS, SS | LB, UB | GR | 0.1m | EC,FF, MD |
| *Pimelodendron macrocarpum* J.J.Sm.; [Euphorbiaceae]; (Perah ikan) | Tree to 18m tall | Lowland swamp forest | Sl, Ml, Jh; Sb & Sw | FS, RS | TF | MS | 3.5m | EX, FF, TS |
| *Piptospatha perakensis* (Engl.) Engl.; [Araceae]; (Keladi) | Herb to 50cm tall | On rocks in flowing rivers and streams | PM: widespread | NS, SS | LB, UB | GR | 0.1m | FF, OR, WQ |
| *Pleiocarpidia enneandra* (Wight) K. Schum.; [Rubiaceae]; | Small tree to 16m tall | Lowland forest including swamps | Pn, Pk, Ph, Sl, Ml, Jh; Endemic to PM | FS, RS, NS, SS | TF | MS | 3m | FF, MD, TS |
| *Polyalthia glauca* (Hassk.) F. Muell.; [Annonaceae]; (Mempisang) | Tree to 45m tall | Lowland swamp forest | Tg, Pk, Ph, Sl, Jh; Sb & Sw | FS, RS | TF | CA | 9m | FF, TS |
| *Polyalthia hypoleuca* Hook. *f.* & Thomson; [Annonaceae]; (Mempisang) | Tree to 30m tall | Lowland and peat swamp forests | Pn, Kl, Tg, Pk, Ph, Sl, NS, Ml, Jh; Sb & Sw | PS, RS | UB, TF | CA | 6m | FF, MD, TS |
| *Pometia pinnata* J.R. Forst. & G. Forst.; [Sapindaceae]; (Kasai daun besar) | Tree to 40m tall | Damp forest in the lowlands and hills | PM: throughout; Sb & Sw | RS, NS, SS | UB, TF | CA | 8m | EC, FF, MD, OR, TS |
| *Pongamia pinnata* (L.) Pierre var. *xerocarpa* (Hassk.) Alston; [Leguminosae]; (Mempari) | Small tree to 20m tall | Inland, often along rivers | PM: all coasts | RS, NS | TF | MS | 4m | FF, MD, OR, TS |
| *Pterocarpus indicus* Willd.; [Leguminosae]; (Angsana) | Tree to 30m tall | Along tidal rivers | Ph, Jh; Sb & Sw | MF, RS | UB, TF | CA | 6m | DT, EX, FF, MD, OR, TS |
| *Rhizophora apiculata* Blume; [Rhizophoraceae]; (Bakau minyak) | Stilt-rooted tree to 30m tall | Mangrove forest | PM: all coasts; Sb & Sw | MF | LB, UB | CA | 6m | DT, EC, FF, FU, TS |
| *Rhizophora mucronata* Lam.; [Rhizophoraceae]; (Bakau kurap) | Stilt-rooted tree to 30m tall | Mangrove forest | PM: all coasts; Sb & Sw | MF | LB, UB | CA | 6m | EC, FF, FU, TS |
| *Rhynchospora corymbosa* (L.) Britt.; [Cyperaceae]; | Herb to 100cm tall | Open swampy places to 1200m | PM: throughout | FS, RS | LB, UB | GR | 0.2m | EC, FB, WQ |
| *Ryparosa hullettii* King; [Flacourtiaceae]; | Shrub or tree to 20m tall | Lowland swamp forest | Tg, Pk, Jh; Sb & Sw | FS, RS | TF | MS | 4m | TS, FF |

| SPECIES DATA | | | | PLANTING DATA | | | | |
|---|---|---|---|---|---|---|---|---|
| Species; [Family]; (Local name) | Habit | Habitat | Distribution | Type of river habitats for planting | Planting zones near river banks | Maximun height/ forest cover | Planting radius/ distance | Socio-economic/ Ecological benefits |
| *Saccharum arundinaceum* Retz.; [Gramineae]; (Tebu) | Reed to 4m tall | Common on river banks | Kd, Tg, Pn, Pk, Ph | RS, NS, SS | LB, UB | GR | 1m | EC, OR, WQ |
| *Sacciolepis indica* (L.) Chase var. *indica*; [Gramineae]; | Herb to 50cm tall | Open grassy and swampy places to 1700m | Pk, Ph, Sl, NS, Ml, Jh | FS, RS, NS, SS, MS | UB | GR | 0.1m | EC, FB, FP, WQ |
| *Saraca cauliflora* Baker; [Leguminosae]; (Gapis) | Tree to 15m tall | Lowland and hill forest, often riverine | Ml and Ph northward | SS | LB, UB | MS | 3m | EC, FF, WQ |
| *Saraca declinata* (Jack) Miq.; [Leguminosae]; (Gapis) | Tree to 15m tall | Lowland and hill forest, often riverine | PM: widespread; Sb & Sw | SS | LB, UB | MS | 3m | EC, FF, WQ |
| *Sarcotheca laxa* (Ridl.) Knuth var. *laxa*; [Oxalidaceae]; | Shrub or tree to 23m tall | Swamps and forest margins | Ps, Kd, Kl, Tg, Pk; Endemic to PM | FS, RS, NS | TF | CA | 4.5m | FF |
| *Schizostachyum gracile* (Munro) Holttum; [Gramineae]; (Buluh) | Bamboo to 4m tall bending over at the top | Forest margins and river banks | Tg, Ph, Sl, NS, Ml, Jh; Endemic to PM | NS, SS | UB, TF | GR | 1m | EC, FF |
| *Schizostachyum latifolium* Gamble; [Gramineae]; (Buluh) | Bamboo to 5m tall | Forest-river boundaries in the lowlands | PM: throughout | RS, NS, SS | UB, TF | GR | 1m | EC, FF |
| *Schizostachyum latifolium* Gamble; [Gramineae]; (Buluh) | Bamboo to 5m tall | Forest-river boundaries in the lowlands | PM: throughout | RS, NS, SS | UB, TF | GR | 1m | EC, FF |
| *Shorea macrantha* Brandis; [Dipterocarpaceae]; (Meranti kepong hantu) | Tree of middle size | Peat swamp forest; | Pk, Ph, Jh; Sw | PS | TF | MS | 3m | TS |
| *Shorea palembanica* Miq.; [Dipterocarpaceae]; (Meranti tekawang ayer) | Tree of middle size | Lowland swamp forest | Tg, Pk, Ph, Jh; Sb & Sw | NS, SS | TF, UT | MS | 3m | TS |
| *Shorea uliginosa* Foxw.; [Dipterocarpaceae]; (Meranti bakau) | Large buttressed tree | Peat swamp forest | Pk, Sl; Sw | PS | TF | CA | 8m | TS |
| *Sonneratia caseolaris* (L.) Engl.; [Lythraceae]; (Berembang) | Tree to 15m tall | Mangroves and tidal river banks | PM: common in the west coast | MF | LB, UB | MS | 3m | DT, FB, FF, MD, TS |
| *Stemonurus secundiflorus* Blume; [Icacinaceae]; (Perepat bukit) | Tree to 12m tall | Forest to 1500m, mostly in lowland swamps | Pk, Ph, Sl, Jh; Sb & Sw | FS, PS, MS | TF | MS | 2.5m | FF, MD, TS |
| *Sterculia gilva* Miq.; [Sterculiaceae]; (Kalumpang) | Tree to 40m tall | Lowland swamp forest | Tg, Pk, Ph, Ml, Jh | FS, RS | TF, UT | CA | 8m | FF, TS |
| *Syzygium cerinum* (M.R. Hend.) I.M. Turner var. *cerinum*; [Myrtaceae]; (Kelat) | Tree to 27m tall | Lowland swamp forest | Pn to Jh | FS, RS | UB, TF | CA | 5.5m | EC |
| *Syzygium foxworthianum* (Ridl.) Merr. & L.M. Perry; [Myrtaceae]; (Kelat) | Small bushy tree | Riverbanks | Kl, Tg, Pk, Ph | FS, RS, NS | UB, TF | GR | 2m | EC |
| *Syzygium leucoxylum* Korth.; [Myrtaceae]; | Tree to 15m tall | Tidal rivers | Pn, Tg, Pk, Ph, Jh | MF, RS | UB | MS | 3m | FF |

| SPECIES DATA | | | | PLANTING DATA | | | | |
|---|---|---|---|---|---|---|---|---|
| Species; [Family]; (Local name) | Habit | Habitat | Distribution | Type of river habitats for planting | Planting zones near river banks | Maximun height/ forest cover | Planting radius/ distance | Socio-economic/ Ecological benefits |
| (Kelat) | | | | | | | | |
| *Syzygium muelleri* (Miq.) Miq.; [Myrtaceae]; (Kelat) | Tree to 22m tall | Lowlands, often near streams | Pk to Jh | RS, NS, SS | UB | CA | 4.5m | EC |
| *Syzygium salictoides* (Ridl.) I.M. Turner; [Myrtaceae]; (Kelat) | Rheophytic shrub | In and near streams | Tg, Ph; Endemic to PM | NS, SS | LB, UB | GR | 1m | EC, WQ |
| *Tarenna odorata* (Roxb.) B.L. Rob.; [Rubiaceae]; | Shrub or small tree to 6m tall | Lowland forest including swamps | Pn, Pk, Sl, Ml, Jh; Endemic to PM | FS, RS, NS, SS | TF | GR | 1m | OR |
| *Terminalia phellocarpa* King; [Combretaceae]; | Tree to 30m tall | Swampy or alluvial forest | Kd, Kl, Tg, Pk, Ph, Sl, NS, Ml, Jh | FS, RS | UB, TF | CA | 6m | MD |
| *Tetramerista glabra* Miq.; [Tetrameristaceae]; (Punah) | Tree to 35m tall | Lowland freshwater and peat swamp forest | Kd, Tg, Pk, Ph, Sl, Ml, Jh; Sb & Sw | FS, PS | TF | CA | 7m | FF, TS |
| *Tristaniopsis whiteana* (Griff.) Peter G. Wilson & J.T. Waterh.; [Myrtaceae]; (Pelawan) | Tree to 24m tall | River banks in the lowlands | PM: widespread; Sb & Sw | RS, NS, SS | UB | CA | 5m | TS |
| *Vatica lobata* Foxw.; [Dipterocarpaceae]; (Resak) | Small tree | Lowland forest near streams | Tg, Ph, Jh; Endemic to PM | RS, NS, SS | UB | GR | 2m | TS |
| *Vatica venulosa* Blume; [Dipterocarpaceae]; (Resak letop) | Small tree | Lowland swamp forest | Pk, Ph; Sb & Sw | FS, RS | TF | GR | 2m | TS |
| *Xylocarpus granatum* J. K"nig; [Meliaceae]; (Nyireh bunga) | Tree to 15m tall | Mangroves | PM: all coasts; Sb & Sw | MF | UB | MS | 2m | FU, TS |
| *Xylopia fusca* Maingay *ex* Hook. *f.* & Thomson var. *fusca*; [Annonaceae]; (Jangkang paya) | Tree to 30m tall | Lowland swamp forest | Kd, NS, Jh; Endemic to PM; Sw | FS, PS, RS | TF | CA | 6m | FF, TS |
| *Zingiber spectabile* Griff.; [Zingiberaceae]; (Tepus) | Herb to about 2m tall | Damp lowland forests | NS northward | NS, SS | TF | GR | 0.4m | FF, MD, OR |

## Abbreviations:

**Distribution:**

PM=Peninsular Malaysia, Ps=Perlis, Kd=Kedah, Pn=Pulau Pinang, Kl=Kelantan, Tg=Trengganu, Pk=Perak, Ph=Pahang, Sl=Selangor, NS=Negeri Sembilan, Ml=Melaka, Jh=Johor, Sb=Sabah, Sw=Sarawak

**Type of river habitats for planting:**

MS=Montane stream, SS=Saraca stream, NS=Neram stream, RS=Rasau stream, FS=Freshwater stream, PS=Peatswamp, MF=Mangrove

**Maximum height/forest cover:**

CA=Canopy, MS=Middle storey, GR=Ground

**Planting zones near river bank (Refer also to Figure 1):**

LB=Lower bank, UB=Upper bank, TF=Terrace face, UT=Upper terrace

**Socio-economic/Ecological benefits:**

BV=Beverages, DT=Dyes and tannins, EC=Ecology/reafforestation, EO=Essential oils, EX=Exudate/resins, FB=Fibre/thach, FF=Fruits, flowers and seeds (food for wildlife), FU=Fuel/charcoal, FV=Vegetables, MD=Medicinal plants, OR=Ornamental, PO=Poison, SF=Spices/flavours, TS=Timber/structure, VO=Vegetable oils, WQ=Water quality improvement

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# End Notes

1 Biodiversity supports ecosystem services which are essentially the multitude of goods and services critical to human well-being provided by ecosystems. These may be classified into four groups: provisioning services such as food and water; regulating services such as flood, pest and disease control; cultural services such as spiritual and recreational benefits; and supporting services such as nutrient cycling, that maintain the conditions for life on Earth.

Changes in these services affect human well-being through impacts on security, the basic material for a good life, health and social and cultural relations. The Millennium Ecosystem Assessment, completed in 2005 by more than 1,360 scientists working in 95 countries, examined the state of 24 services. The assessment concluded that 15 of the 24 services are in decline, including the provision of fresh water, marine fisheries production and the number and quality of places of spiritual and religious value. The multitude of human drivers of change has significant negative repercussions on the ability of ecosystems to provide these services to all species. Two drivers – accelerated climate change and excessive nutrient loading – are predicted to become more severe in the next 50 years. For more information, go to: www.milleniumassessment.org

**Table:** Biodiversity and ecosystem services

<table>
<tr><th colspan="6">Biodiversity & ecosystems</th></tr>
<tr><th colspan="2">Provisioning services</th><th colspan="2">Regulating services</th><th colspan="2">Cultural services</th></tr>
<tr><td colspan="2">Products obtained from ecosystems</td><td colspan="2">Benefits obtained from regulation of ecosystem processes</td><td colspan="2">Non-material benefits obtained from ecosystems</td></tr>
<tr><td colspan="2">• Food<br>• Fresh water<br>• Timber<br>• Fuel wood<br>• Fibre<br>• Biochemicals<br>• Genetic resources</td><td colspan="2">• Climate regulation<br>• Pest regulation<br>• Runoff/flood regulation<br>• Water purification<br>• Pollination<br>• Erosion regulation</td><td colspan="2">• Spiritual & religious<br>• Recreation & ecotourism<br>• Aesthetic & inspirational<br>• Educational<br>• Cultural heritage</td></tr>
<tr><th colspan="6">Supporting services</th></tr>
<tr><td colspan="6">Services necessary for the production of all other ecosystem services</td></tr>
<tr><td>Soil formation</td><td>Nutrient cycling</td><td colspan="2">Primary production</td><td>Provision of habitat</td><td>Oxygen production</td></tr>
</table>

Adapted from: A Common Vision on Biodiversity (NRE, 2008)

2 **Biological interactions** are essentially the relationships between two species in an ecosystem. These relationships are categorised based either on the effects or on the mechanism of the interaction. Species may meet once in a generation (e.g. pollination) or live completely within another (e.g., endo-symbiosis). Effects may range from one species eating the other (predation), to both living together with mutual benefit (mutualism). There is also (commensalism) where one of the organisms benefits and the other neither benefits nor is harmed. Competition is the utilisation of limited resources by two or more organisms. The interactions between two species need not be through direct contact. Due to the connected nature of ecosystems, species may affect each other through intermediaries such as shared resources or common enemies.

3 **Nitrogen** is most commonly transported as dissolved nitrogen (nitrates) through subsurface flows (Pionke et al., 1996). The primary mechanism for nitrate removal by riparian forests is

denitrification, which is a process whereby nitrogen in the form of nitrate ($NO_3$) is converted by microorganisms to gaseous $NO_2$ and $N_2$ and released into the atmosphere. In order for denitrification to occur, certain soil conditions must be present:

1) a high or perched water table;
2) alternating periods of aerobic and anaerobic conditions;
3) healthy populations of denitrifying bacteria; and
4) sufficient amount of available organic carbon.

Denitrification is most effective in root-zone soil layers where carbon sources are available for the denitrifying bacteria. Numerous researchers have reported that it is the complex interaction between vegetation and below-ground environment that provides the appropriate conditions for denitrification to occur (Lowrance et al., 1995). The majority of denitrification that has been observed in riparian buffers occurred within the first 4.5m of the forested riparian buffer.

Vegetation in riparian buffers also removes nitrogen and phosphorous through uptake. Some of these nutrients are sequestered in woody vegetation, whereas the nutrients absorbed into herbaceous (e.g. leaves) materials are recycled as the vegetative matter dies.

**Phosphorus** most often enters the stream adsorbed into soil particles and organic materials in surface runoff after storm events (Pionke et al., 1996). Although riparian zones can be important sinks for phosphorus, they are generally less effective in removing phosphorus than sediment or nitrogen.

The primary mechanism for phosphorus removal by riparian buffers is the deposition of phosphorus associated with sediments. In addition to the settling of particulate phosphorus, dissolved phosphorus may also be removed from runoff through adsorption by clay particles, particularly where there are soils containing clays with high levels of aluminum and iron. Some have suggested that because clays tend to accumulate in riparian soils, riparian areas play an important role in the removal of dissolved phosphorus (Walbridge and Struthers, 1993). However, others have found that soils are limited in their capacity to adsorb large loads of phosphorus, and in areas where excessive phosphorus enrichment occur, soils become saturated within a few years (Mozaffari and Sims, 1994).

Unlike nitrogen, phosphorus absorption is reduced in soils with high organic matter (Walbridge and Struthers, 1993). Some phosphorus may be taken up and used by vegetation and soil microbes, but like nitrogen, much of this phosphorus is eventually returned to the soil.

Many factors influence the ability of the riparian buffer to remove **sediments** from land runoff, including the sediment size and loads, slope, type and density of riparian vegetation, presence or absence of a surface litter layer, soil structure, subsurface drainage patterns, and frequency and force of storm events.

Probably the most important consideration is the maintenance of shallow sheet flow into and across the buffer. Where concentrated flow paths (e.g. rivulets) begin to form or deep sediments begin to accumulate, the buffer can no longer maintain its filtering ability.

Few studies have been done to examine the fate of **pesticides** in riparian areas. However, where the proper conditions exist, riparian forest buffers have the potential to remove and detoxify pesticides in runoff. Pesticides, like other organic chemicals, are acted upon by various chemical and biological processes in the soil environment. Probably the most important process is the breakdown of organic chemicals by soil microorganisms (MacKay, 1992). Soil microorganisms adapt to the presence pesticides and begin to metabolize it as an energy source. As it is metabolized, the pesticides are broken down to various intermediate compounds, and ultimately carbon dioxide. In addition, most pesticides have a high affinity for clay and organic matter, and may be removed from the soil water as they are bound to soil particles.

Analysis of the woody tissues of trees in the riparian zone reveal that **metal** compounds are taken up by the trees. Therefore, sediment deposition and uptake by woody vegetation may help mitigate heavy metals in riparian areas (Hupp et al., 1993).

4 **Hydrology**, i.e. the speed, depth and pathways in which water moves through or over the buffer is the most important factor which determines the effectiveness of riparian buffers. Hydrology in

the riparian zone is influenced by local geology, topography, soils and catchment characteristics.

In areas where slope is minimal and surface water flows are slow, shallow and uniform, riparian buffers can be highly effective in slowing the force of stormwater and reducing the amount of sediment, crop debris and other particulate materials that reach streams.

However, riparian buffers are not effective when deep groundwater flow paths cause drainage to bypass (flow below) the riparian zone. For example, in order for nitrate to be removed through denitrification, the ground water must enter a zone where plant roots are or have been active.

Sediment and sediment-associated pollutants, such as some pesticides and phosphorus, move to surface waters almost exclusively through surface runoff. Therefore, when surface runoff becomes concentrated and runs through the buffer in defined channels (usually due to a lack of vegetation), the ability of the buffer to influence surface waters is limited.

[5] **Soils** in riparian zones are highly variable; a combination of local soils weathered in place, deposits of sediments from storm events and the accumulation of organic debris (Lowrance et al., 1985). Soil features which influence water quality include the depth to the water table, soil permeability, texture, chemistry and organic matter content (US EPA, 1993). These features affect the way and the rate at which water flows over and through the riparian area, the extent to which groundwater remains in contact with plant roots and with soil particles and the degree to which soils become anaerobic.

Riparian forests with organic soils have great potential to enhance water quality, by infiltrating a large amount of surface runoff, adsorbing nitrogen and other contaminants and supplying carbon needed to fuel microbial processes. Many of the water quality functions of the riparian area are a result of the activity of soil microorganisms. Soil microorganisms influence water quality in several ways. Like plants, microorganisms take up and convert nutrients to forms which are less biologically available and more readily stored in the soil. Soil microorganisms also utilise and metabolise organic chemicals such as pesticides as energy sources and in the process, transform the chemicals to less toxic compounds. Finally, soil microorganisms are responsible for many chemical reduction reactions that occur in the soil, including denitrification and the reduction of sulphur, iron and other compounds (Mitsch and Gosselink, 1993).

[6] **Silviculture** is the art and science of controlling the establishment, growth, composition, health and quality of forests.

[7] Also refer to the **Urban Stormwater Management Manual for Malaysia** (DID, 2000), which provides a list of recommended plant species, together with the specific functions of each species such as for pollution control and slope stabilisation.