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Introduction

Riparian (or riverine) forests occur as strips or belts of special forest types lining streams and rivers, and influenced by the presence of the river in one way or another. Streams and rivers are characterized by moving water, - normally unidirectional, but seasonal inverse direction does occur. Rehabilitation of river habitats is one of the major forest restoration efforts throughout the world. Rivers are naturally in a dynamic equilibrium undergoing a range of river processes. However, very disturbed river habitats are fragile and degradation may be self-perpetuating, e.g. if disturbance leads to increase flooding which causes stream-bank collapse leading to further destruction downstream. Riparian forests are the key element of watershed management, i.e. flow from the entire drainage area. In addition, riparian forests are often prone to heavy degradation, firstly because the riparian environment is conducive to produce large valuable timber trees, secondly because transport of logs is easy on rivers, and thirdly because human settlements including their clearance for agriculture is usually near the rivers. Nowadays, many rivers are exposed to heavy loads of human waste, both organic and inorganic.

Restoration of riparian forests has a dual purpose *viz*. restoring physical environment as well as the biological environment. Physical restoration refers to re-establishing the power of natural river dynamics. This include firstly to stabilise drainage and water-flow in rivers, and secondly to minimise erosion and water siltation. Protecting and restoring rivers and watershed is usually high priority areas for environmental protection because rivers affect downstream areas. Or: any disturbance upstream will have a usually negative effect on communities and cultivation areas downstream. Trees have a key role in protecting stream-bank erosion, siltation of water and buffer watershed (i.e. prevent drought and flooding). In addition, trees are the main component of the biological environment,and riparian forests are important ecological corridors.

Riparian forest types

Soil, topography and variation in water flow are some of the main physical determining factors for forest types and species composition. Where rivers cut through steep landscape, their presence may be limited to a narrow strip of 'gallery forest'. Where landscape is flat, rivers may be surrounded by large patches of seasonally flooded forest. Lengthwise, vegetation changes from the origin of springs or founts, to the merging with other rivers and eventually outlet in river deltas. Around springs there is less water movement and forest is a type of swamp forest, often

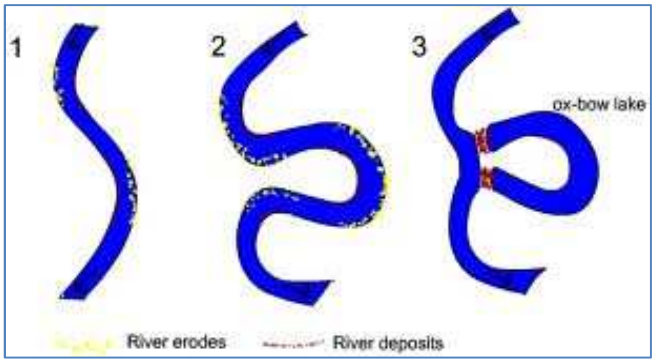

Figure 1. Development of a meandering system and formation of an 'ox-box lake'

with relatively few species tolerant to long periods of water logging for example *Barringtonia* species, which also occur in flooded or inundated forest. Swamps and ponds may also be found downriver where meandering and change of riverbeds leave sections of the main river isolated from the main current, sometimes seasonal, sometimes as permanent small lakes (ox-bow lakes). Along rivers species diversity is often high with many large trees including *Gluta, Ficus*, dipterocarps

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and Myristicaceae. River deltas are often flooded and exposed to salt water influx from sea water, especially in tidal areas. There are fewer adapted species for example *Nypa* palms, and mangrove species such as *Avicennia* and species of Rhizophoraceae.

River-bank degradation

Critical areas are sections of rivers where the natural dynamics have been disturbed to an extent where natural recovery is very slow. Most such sites are in the immediate vicinity of rivers, i.e. river-banks. Threat to riverbanks may come from the river-ward side or the landward side. Both are usually caused by removing trees.

a) From the land ward side, removal of trees cause reduced interception and increase surface flow and interception, which leads to erosion and sometimes landslides.

b) From the riverward side removal of trees implies increase the direct water current contact with soil and aggravates riverward erosion. Erosion may lead to undercutting of higher riverbanks and root systems of larger trees causing bank collapse, landslide and fall of trees

Figure 2: Damaged riverbank. As the vegetation is destroyed the banks are prone to physical impact by the water

Erosion is a product of water flow: where flow is high, river-banks are more exposed. A meandering river is more prone to erosion on inside of the meander than on the outside. Degradation may be self-perpetuating: Once vegetation has been reduced the soil is left more open causing even higher rates of erosion. Since erosion is a product of water-impact, the more water the higher the erosion. Hence, downstream areas of large rivers have potentially much higher erodibility than upstream areas with lower water impact.

Deforested areas are likely to cause increased runoff because water is not absorbed by the vegetation. This may not be easily visible on the sites themselves, but the effects can still be serious. This type of critical site may be in any area of the watershed area, from hill forests to riparian forests.

Flooded forest that has lost a major portion of its tree cover will have reduced buffering effects on lands behind and downstream. Removal of trees in flooded forests causes the water speed to increase. Flooding and drainage occurs at a higher rate and hence the fluctuations of the area downstream.

Selective logging of valuable riparian trees results in a relative enrichment with poor value tree species e.g. *Ficus spp*. and *Gluta rengas*.

Restoring riverbanks

Advanced physical degradation e.g. riverbank erosion, landslides and collapse implies some difficulties because the soil is continuously exposed to the forces of water currents. New plants are generally more vulnerable to physical tearing, uprooting and risk of being coved by sediments than larger and established plants. At severe sites, restoration may require both physical restoration and tree planting.

Physical restoration involves fixing soil by erosion barriers until plant roots have established a protecting root net. Stones, boulders, strong wire netting and wooden structures are among some solutions that are effective but unfortunately rather labour demanding. The physical structures should aims at preventing undercutting of banks and halt slides.

Restoration activities must be undertaken when water level is low. Physical restoration is carried out where erosion is severe or threatening to e.g. houses or fields.

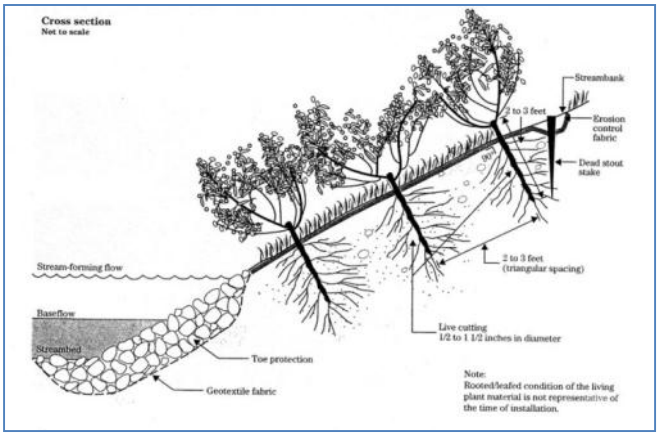
Figure 3. *Gluta renghas* . The species is usually left because the sawn timber causes strong allergic reaction in the form of skin rashes

Restoration of collapsed riverbanks with tree planting starts 'from behind' i.e the sites farthest away from the river. The rationale is firstly that unstable sites must be

fixed to avoid them making an impact on even more instable and more exposed sites next to rivers, secondly to avoid plants being destroyed by water currents (fig.4).

Behind the active riverbed

Restoration of riparian forest behind the active riverbed is easier in the sense that there is less risk of physical stress from water current. Restoration here involves traditional restoration techniques like ANR, enrichment planting, and release thinning. Felling of riverine forests tends to favour light loving herbal and woody pioneers e.g. bushes, wines and rattans, which may temporarily suppress the juvenile up-growth of new long-living woody species.



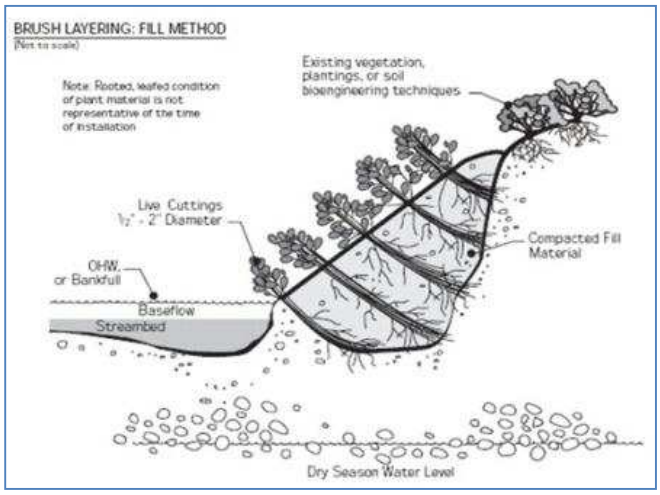


Figure 4. Physical and biological restoration of eroded and collapsed riverbeds. Eroded sites are stabilised with stones or compacted material and plants are established by rooting of large cuttings (stake propagation). Plant roots will bind the soil and improve the physical resistance to erosion

Planting material

Plants can be raised and established as seedling plants or vegetative propagules. The advantage of the latter is that a root net is already established which can develop as the plant grows. It requires, however, a nursery period, which implies a certain cost.

Alternatively, several riparian species can be propagated by on-site stake (long) cuttings. This has the advantage, in addition to saving nursery cost that the stakes have themselves a certain mechanical resistance, which is improved as the stakes root and grow. Following riparian species can be propagated by rooting of stakes on-site:

Barringtonia spp. / *Peronema canescens / Neonauclea / Nauclea / Anthocephalus / Neolamarckia / Ficus* spp.

<u>Species selection</u>

Following species are among species suitable for forest restoration of riparian forests in Indonesia:

1. Upstream river source with long term waterlogged conditions. Also suitable for swamps around ox-bow lakes and other cut-off river sections: *Actinodaphne glomerata, Alstonia pneumatophora, Aporosa lucida, Baccaurea bracteata, Baccaurea deflexa, Baccaurea macrocarpa, Barringtonia spp,, Bhesa paniculata, Buchanania arborescens, Carallia bractiata, Diospyros macrophylla, Endospernum diadenum, Ganua motleyana, Garcinia parvifolia, Gironniera nervosa, Horsfieldia irya, Knema conferta, Licuala spinosa, Livistona* spp,, *Myristica elliptica, Stemonorups secundifolius, Syzygium laxiflorum, Terminalia subspathulata, Tetramerista glabra*
2. Riverbanks and exposed sites. Include species with high soil binding capacity, resistance to mechanical tearing and large trees potentially forming gallery forests. *Actinodaphne glomerata, Anthocephalus cadamba, Aporosa nitidia, Archidendron jiringa, Artocarpus anisophyllus, Artocarpus elasticus, Baccaurea bracteata, Baccaurea deflexa, Baccaurea macrocarpa, Barringtonia racemosa, Beilschmiedia kunstleri, Bhesa paniculata, Blumeodendron tokbrai, Buchanania arborescens, Calophyllum inophyllum, Caryote mitis, Cratoxylum arborescens, Cratoxylum cochinchinensis, Cratoxylum formosum, Dacryodes rostrata, Dacryodes rugosa, Dehaasia caesia, Dialium indum, Dialium platysepalum, Diospyros macrophylla, Diospyros malabárica, Dipterocarpus palembanicus, Dryobalanops oblongifolia, Eusederoxylon*

zwageri, Fagraea fragrans, Flacourtia rukam, Garcinia parvifolia, Geunsia pentandra, Gironniera nervosa, Gluta renghas, Gynotroches axillaris, Hopea mengerawan, Horsfieldia irya, Knema conferta, Koompassia excelsa, Koompassia malaccensis, Lithocarpus elegans, Lithocarpus lucidus, Livistona spp, Mallotus paniculatus, Mangifera griffithii, Meliosma sumatrana, Myristica elliptica, Myristica máxima, Ormosia sumatrana, Peronema canescens, Podocarpus neriifolius, Polyalthia cauliflora, Porterandia anisophylla, Pternandra coerulescens, Pternandra cordata, Scapium macropodum, Scorodocarpus borneensis, Sindora leiocarpa, Syzygium laxiflorum, Terminalia subspathulata, Tetramerista glabra, Xerospermum noronhianum.

3. Riparian forests behind the main active riverbed. Tolerant to seasonal water-logging. *Anthocephalus cadamba, Archidendron jiringa , Calophyllum macrocarpum, Calophyllum inophyllum, Cratoxylum arborescens, Cratoxylum cochinchinensis, Cratoxylum formosum, Dacryodes rostrata, Dacryodes rugosa, Dehaasia caesia, Dialium indum, Dialium platysepalum, Diospyros macrophylla, Diospyros malabárica, Dipterocarpus palembanicus, Durio griffithii, Eleiodoxa conferta, Eusederoxylon zwageri, Flacourtia rukam, Garcinia parvifolia, Gluta renghas, Hopea mengerawan, Horsfieldia irya, Intsia palembanica, Knema conferta, Koompassia excelsa, Koompassia malaccensis, Lithocarpus elegans, Livistona spp,, Myristica elliptica, Pometia pinnata, Porterandia anisophylla, Scapium macropodum, Scorodocarpus borneensis, Sindora leiocarpa, Syzygium laxiflorum, Terminalia subspathulata, Tetramerista glabra*.

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