# DYNAMICS, THREATS, RESPONSES, AND RECOVERY OF RIVERINE-RIPARIAN FLORA

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## Contents

**Summary**

The flora of river ecosystems encompasses a variety of situations and a range of communities associated with the river and its floodplain. The marginal and emergent zone is an important element of the stability of streams and rivers but equally critical is the transition from water to land. The bank side communities are a continuation of this ecotone, providing habitats such as riparian forests, establishing a buffering system between the landward process, and influencing the quality of river water. Riparian forests are relatively small areas and may be vulnerable to alterations. Aquatic macrophytes have adapted to an amphibian life while protecting river banks and are functionally important. Productivity is the formation of organic material averaged over some period of time; for running waters it is mainly determined by the algal biomass presence in the water and shows great variability in species and abundance.

These components of the flora of river systems are a part of the continuum and the article concludes by considering the integrated nature of various communities through dynamics and the need for restoration to recover from associated natural as well as human induced disturbances. It also considers the importance of measuring and monitoring the disturbances that place stresses on ecosystems by changing community or population structure, changing resources, reducing substrate availability, or changing the physical environment that needs to protect any natural reserve.



## 1. Introduction

Rivers and their floodplains are amongst the most fragile and threatened ecosystems in the world and the stresses associated with local environments through anthropogenic activities have a long history because of their importance as sources of water for agriculture as well as transportation routes when roads were few and also as sources of power when the Industrial Revolution was in its infancy.

The way river and stream ecosystems are currently used and managed is causing increasingly severe ecological deterioration, particularly through factors such as hydrological energy production and dams, intensive agriculture, deforestation of river basins, intensive use of agrochemicals, pollutants from industries in the river vicinity, urbanization of river corridors, drainage, river regulation and flood defense schemes. And these stresses further continue as extensive commercial navigation of rivers, which has resulted in much artificial improvement of natural channels, including increasing the depth of the channels to permit passage of larger vessels.

Developments and all other anthropogenic activities associated with riverine localities may alter the ecology of rivers, which will affect the productivity and stability of these fragile but dynamic systems. Natural functions of rivers are mostly dependent on the dynamics of associated floral ecosystems such as riparian zones, macrophytes, and algae.

Certain characteristics of a river or stream distinguish it from other aquatic environments. Rivers and streams have a unidirectional flow, fluctuating discharge, and unstable channel and bed morphology. The shearing action of flowing water results in scoring, transport, and deposition of bed and bank materials, and a continually changing physical environment. River channels evolve in response to climate, geology and weathering, and the forces involved in shaping and maintaining the channel are related to fluid flow. From a biological point of view, running water has several benefits over still water, despite the stress imposed on biota; it is constantly mixed by turbulence providing nutrients, exchange of respiratory gases, and removal of wastes. Many of the biological features of running water are determined by these physical properties of the environment.

In catchments and along rivers that are located near urban centers (e.g., Santa Cruz River, southern Arizona; see http://ag.arizona.edu/watershed/scruz.html) the floral systems are increasingly threatened as rivers lose their natural dynamics. It has been predicted that by 2025, 80% of the world's people will be living in cities, so we need to protect their environment. As one example from recent history, between 1973 and 1992, 154 000 hectares (380 000 acres) of trees were lost from the urban areas of Atlanta, a rate of 22 hectares (55 acres) per day. So the future of these fragile systems is far from secure.

In spite of the availability of advanced waste-purification technology, a surprisingly large percentage of the sewage from cities and towns is released into waterways untreated. In effect, rivers are used as open sewers for municipal wastes, which results not only in the direct degradation of water quality but also in eutrophication. As a consequence of human interventions, some species of both flora and fauna not only within the river but also in catchments have disappeared; exotic species have invaded, the functional characteristics of the river systems have been disrupted, and there has been a reduction of landscape quality and loss of wilderness areas (e.g., The Willamette River in northwestern Oregon; see http://www.epa.gov/docs/fedrgstr/EPA-IMPACT/.html).

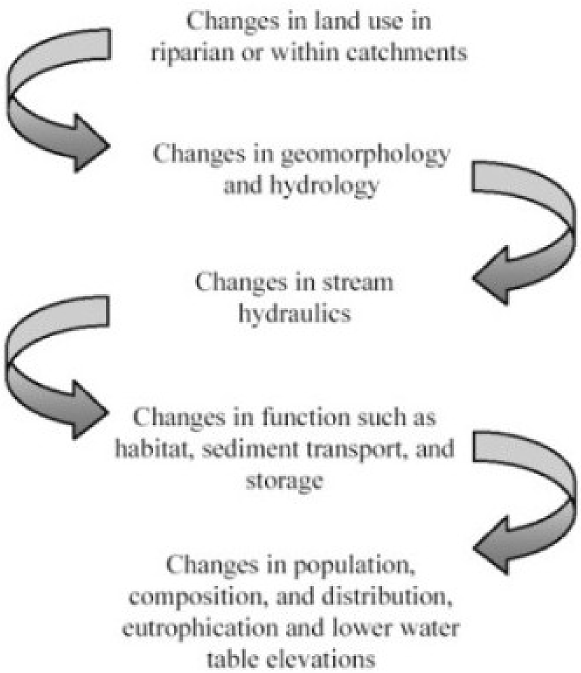


Figure 1. Resulting chain effects due to natural or human induced disturbances that may permanently alter one or more characteristics of a stable system (Source: FISRWG (1998). *Stream Corridor Restoration: Principles, Processes, and Practices*. The Federal Interagency Stream Restoration Working Group (FISRWG))

Natural events or human induced activities that occur separately or simultaneously can bring changes to the river ecosystem (Figure 1). A disturbance occurring within the system typically produces a causal chain of effects, which may permanently alter one or more characteristics of a stable system.

River ecosystems exhibit a dynamic form of stability although they are constantly changing. Stability is the ability of a system to persist within a range of conditions and this phenomenon is referred to as dynamic equilibrium. Stability of ecosystems combines the concepts of resistance, resilience, and recovery. Resistance is the ability to maintain original shape and functions. Resilience is the rate at which a system returns to a stable condition after a disturbance while recovery is the degree to which a system returns to its original condition after a disturbance.
Many river ecosystems can accommodate quite significant disturbances and still return to functional condition in a reasonable time frame, once the source of the disturbance is controlled or removed. Often the elimination of stress and the time to recover naturally are an economical and effective restoration strategy.

This article reviews the importance of riparian forests, aquatic macrophytes and instream algae, temporal and spatial changes related to river dynamics, associated disturbances and recovery after removal of disturbances.

## 2. Riparian Forests

The ecological integrity of river ecosystems is directly related to the integrity and ecological characteristics of the plant communities that make up and surround the river catchments. Riparian vegetation refers to the vegetation that grows along the shores of rivers. Riparian comes from the Latin *ripa*, meaning a stream or river bank. These plant inhabitants are a valuable source of energy for the biological communities, which provide physical habitats, moderate solar energy fluxes, and form surrounding aquatic and terrestrial ecosystems.

Riparian forests are essential components of the structure and function of a healthy river ecosystem as these areas directly interact between terrestrial and aquatic environments. On the other hand, riparian forests are highly disturbed by floods, which have a strong effect on the irregular topography of the valley floor; flood events and soil moisture, which is extremely varied over short distances, affect the structure and dynamics of the plant community. These forces, which cause frequent and intense disturbances, may interact to control the patterns and species richness of the specific ecosystem, resulting in a dense mosaic strip of habitats along the riverbank and segregation of species at local scale.

Moderate water temperatures, maintained by riparian vegetation, are essential to protect against rapid fluctuations that can harm stream health and reduce fish spawning and survival. In a small stream, temperatures may rise 1.5 degrees Celsius in just 100 feet of exposure without trees. The leaf canopy also improves air quality by filtering dust from wind erosion.

## 2.1 Nutrient Cycling

A great number of headwater streams begin in forest zones where there is extensive cover by riparian vegetation. Through the growth cycle of different plant species of riparian forests, a portion of photosynthetically produced organic materials are stored as above- and below-ground biomass, while a significant fraction of organic matter is lost annually via senescence, fractionation, and leaching to the organic soil layer in the form of leaves, twigs, and decaying roots. This fraction of organic materials is rich in microbial flora and microfauna which have major storage and recycling pools of available carbon, nitrogen and phosphorus, and other minor nutrients. Allochthonous organic materials are important for the trophodynamics of streams and influence on channel morphology, which will increase habitat diversity. The quantity and quality of allochthonous materials entering the lotic system depends upon the productivity and environmental history of the adjacent riparian zone.

Rain that runs off the land can be slowed and infiltrated in the forest, which helps settle out sediment, nutrients, and pesticides before they reach streams. Infiltration rates 10–15 times higher than grass turf and 40 times higher than a plowed field are common in forested areas. Studies have shown dramatic reductions of 30–98% in nutrients (nitrogen and phosphorus), sediment, pesticides, and other pollutants in surface and groundwater after passing through a riparian forest.

## 2.2 Distribution and Composition

The distribution and composition of plant communities are determined by climate, amount of available water, topographic features, nutrient content, and physical properties of the soil. Also, the composition and regeneration patterns of vegetation are characterized in terms of horizontal complexity while species composition and age structure of riparian vegetation are described by vertical complexity. Diverse riparian forests with varied vertical and horizontal structural properties can support a far more diverse faunal community beneficial for the healthy and long-lasting dynamics of the ecosystem.

The composition of the plant communities directly influences the diversity and integrity of the associated fauna. Numerous animal species are associated with particular plant communities; many require particular developmental stages of those communities, and some depend on particular habitat elements within the communities. Also, the structure of river bank vegetation directly affects aquatic organisms by providing inputs of appropriate organic materials to the aquatic food web, by shading the water surface and providing cover along banks, and by influencing instream habitat structure through inputs of woody debris.

In explaining species distribution, age structure, floral composition, vertical and horizontal distribution can be extremely important. Vertical complexity itself describes the concept of diversity of strata or foliage height diversity in ecological literature (for more details see FISRWG, 1998).

The river continuum concept, as described earlier in this article, is also generally applicable to the vegetative components of the river riparian zones. The concept is an attempt to generalize and explain longitudinal changes in river and stream ecosystems. This conceptual model helps to identify connections between the watershed, floodplain, and stream systems and it further explain show biological communities develop and change from the headwaters to mouth.

## 2.3 Habitats Based upon Riparian Forests

Riparian forests offer a tremendous diversity of habitats. The layers of habitat provided by trees, shrubs, and grasses and the transition of habitats from aquatic to upland areas make these areas critical in the life stages of all inhabitants. Most riparian forests show a characteristic transpiration gradient and an intra-riparian gradient that support a moister microhabitat than occurs on the surrounding slopes. The moist, cooler edaphic and atmospheric nature is conducive to plant and animal species at lower than normal altitudes, often disjunction populations or in regions where they would not otherwise occur. It has been found that some forest corridors provide a crucial migratory habitat for neotropical songbirds, some of which are now threatened due to loss of habitat.

Dense growth of riparian vegetation can produce a matrix of exposed roots (e.g., *Salix*, *Alnus*, *Acer*, *Phalaris carex*), especially where the toe of bank is scoured. These roots are important habitats for specialized and rare insects, such as Trichoptera and Ephemeroptera. Also it has been found that the macroinvertebrate species are often significantly associated with leaf litter as individuals or as groups. Litter and its associated aquatic macroinvertebrates show potential benefits to the stream economy in three main ways:

- As a direct food resource for the "shredder" feeding guilds.
- As an indirect food resource and as a site for production (via micro-heterotrophs) and capture of fine particulate organic matter.
- As a physical substrate, increasing the available surface area, especially when leaf packs accumulate; and introducing large-scale structure of fine sediment.

Further, species and age structure of vegetation is extremely important. Simple vegetative structure, such as a herbaceous layer without woody overstory or old wood riparian trees without smaller size classes, creates fewer niches for guilds. The presence of fewer guilds implies the presence of fewer species or low diversity. The quality and vigor of the vegetation can influence the productivity of fruits, seeds, roots, and other vegetative material, which provide food for the existence of wild life. Poorer vigor can result in less food and fewer consumers.

Also, many ecologically important species such as herons, wood ducks, black ducks, as well as amphibians, turtles, foxes and eagles, utilize the riparian forest. The decline of these species is partly due to destruction of habitat, which extends well into small streams.

### 2.4 Succession

Plant communities are dynamic and change over time. Varying regeneration strategies of different vegetation types lead to specific patterns of plant succession following disturbances, in which dominant species well adapted to bare soil and plentiful light are gradually replaced by longer-lived species that can regenerate under more shaded and protected conditions. New disturbances reset the successional process. Riverine plant communities are disturbed by factors such as flood depth, duration, and frequency, as well as variations in soil and drainage conditions. Some plant species (e.g., cottonwood (*Populus* sp.), willow (*Salix* sp.)) are adapted to colonization of newly deposited sediments and may require very specific patterns of flood recession during a brief period of seedfall to be successfully established. This will result in an evenly aged tree community established at different intervals and locations within the active meander belt of rivers.

## 3. Aquatic Macrophytes

Aquatic macrophyte vegetation is a key element of biota and ecology of most river systems, providing much of the primary production, and thus food, as well as amphibian habitats. Macrophytes comprise a diverse group of plants that have become adapted from terrestrial species to life wholly, or partially, in freshwater. "Aquatic" plants are defined (see Cook, 1974) as those whose photosynthetically active parts are permanently or, at least, for several months each year submerged in, or floating on, freshwater. This explanation allows separation between the truly aquatic species and those that tolerate only occasional high flood stages or, as with many riverbank trees, are rooted in saturated substrata. Aquatic plant habitats are varied and diverse due to the wide range of plant morphologies and colonization patterns associated with different plant species such as aquatic spermatophytes (seed-bearing plants), pteridophytes (ferns and fern allies), bryophytes (mosses and liverworts), and some macroscopic algae (*Chara* and *Nitella*).

### 3.1 Types of Macrophytes

Although various subdivisions and terminologies have been proposed, macrophytes are often classified in a simple four-group system by their growth habitat, a system that is widely accepted and applied in practice, rather than taxonomically.

1. Emergent macrophytes, which are rooted plants with most of their leaves and stem tissue above the water surface (e.g., *Phragmites* spp., *Sagittaria* spp.).
2. Floating-leaved macrophytes, which are rooted plants with most of their leaf tissue at the water surface (e.g., *Nymphaea alba, Nymphoides peltata*).
3. Free-floating macrophytes, which are not rooted to the substratum but live unattached within or upon the water (e.g., *Ceratophyllum demersum, Eichhornia crassipes*).
4. Submerged macrophytes, which are rooted plants with most of their vegetative tissue beneath the water surface (*Hydrilla verticillata, Ranunculus penicillatus*).

### 3.2 Adaptations

As all freshwater macrophytes have evolved from terrestrial species, either by reduction of terrestrial characteristics or by evolving secondary adaptations, these specialized adaptations exhibited by macrophytes in rivers are evolutionary adaptations to the aquatic environment. Among these adaptations, the most significant one is the gas diffusion difference between terrestrial and aquatic environments. With compared to terrestrial environments, aquatic environments have much slower (10 000 times low) rates of gas diffusion. The second is the reduction of light, which divide into several fractions after incident to the water surface such as reflection, absorption and scatter that will limit the usable amounts for photosynthesis. A major adaptation to these restraints is the formation of aerial leaves, as seen in the emergent, floating leaved and surface free-floating species. Also, more specialized adaptations can be found for the growth of submerged tissues including thin leaves lacking an epidermis, internal gas transfer, and specialized photosynthetic physiology.

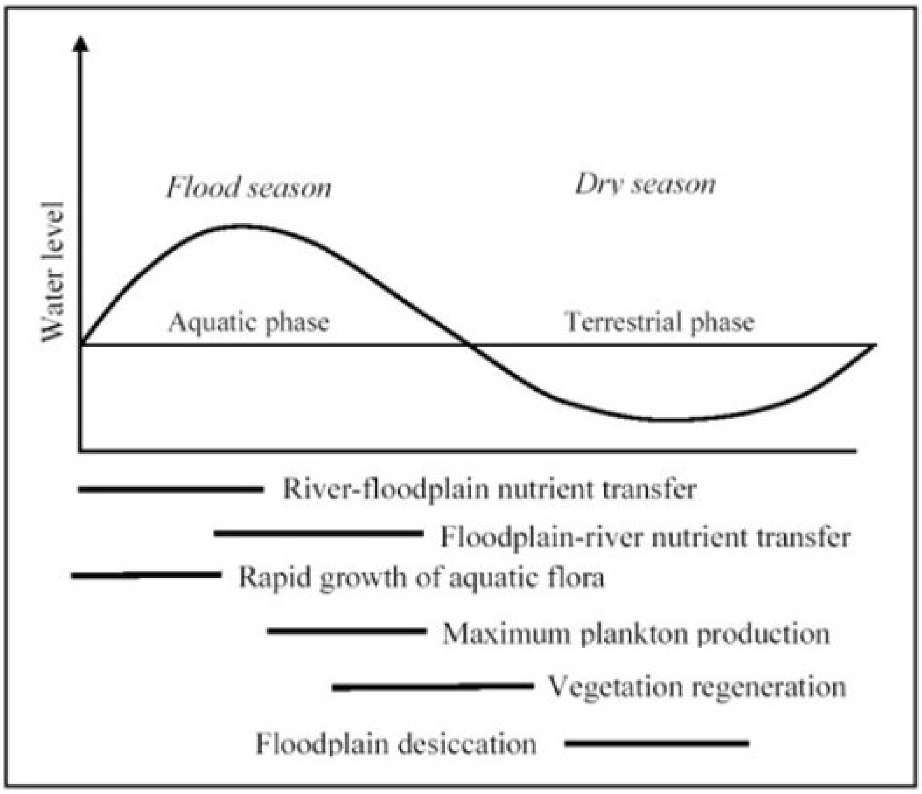


Figure 2. Adaptations to the land water interaction within fluvial hydrosystems. (Adapted from Ward J. V. (1989). The four-dimensional nature of lotic ecosystems. *Journal of the North American Benthological Society* **8**, 2–8)

Figure 2 illustrates some of the adaptations of macrophytes for land water interaction. The absence of a species is determined by intolerance to extremes of abiotic environment. Water movement is one of the most important and specific abiotic variables influencing species composition and location of plant communities in rivers. There can be direct and indirect effects on vegetation related to aspects of water movement such as velocity, turbulence, and erosive forces. It has been found that photosynthesis increases in relation to water velocity increase in riverine *Ranunculus* species, which may occur for several reasons: reduction in thickness of the boundary layer surrounding the macrophyte leaves with increasing water velocity may ease diffusion of carbon dioxide across this layer; higher velocities tend to be more turbulent and increase the aeration of water, which will improve photosynthesis providing carbon dioxide; this will expose macrophytes to a constantly replenished source of nutrients.

### 3.3 Habitats Based upon Macrophytes

There has been increasing interest in recent research in the formation of aquatic habitats by macrophytes and their importance to the river system. Aquatic macrophytes' habitats are varied and diverse due to the wide range of plant morphologies and colonization patterns associated with different plant species. Trailing plant species (e.g., *Ranunculus* spp. tend to form large dominant stands in suitable rivers) provide a greater range of habitats and a different type of habitat to that provided by floating leaved plants (e.g., *Nuphar* spp. tend to be found in smaller clumps, along with various other plant species). Emergent plants (e.g., *Phragmites* spp.) provide different habitats and are found colonizing the slow-flowing shallow waters at river margins.

Macrophyte vegetation is important to periphyton grazers such as chironomids and gastropods. Also macrophytes provide a substrate for periphyton species and can differ between macrophyte species, producing a diverse environment of selective grazers. Plants with dissected leaves consistently support more invertebrates than those with broad leaves and fine-leaved plants might provide more surface area for growth of periphyton as well as other invertebrates. Riverine margins are relatively less studied but much of the research in this field has concentrated on the nuisance species that interfere with water use, and concerns over the restoration and protection of natural systems. However, they may be the first area to recover habitat complexity in rivers. Shallow vegetated low current areas are selected by many planktivorous fish as a refuge from predation. Also, it has been found that aquatic macrophytes may perform a role of habitat segregation, as large fish predators cannot freely move through dense vegetation (see Priyadarshana et al., 2001). Aerial parts of marginal and emergent vegetation provide a good habitat for terrestrial insects. Furthermore, mature stages of aquatic invertebrates use this vegetation zone for feeding, mating, and oviposition, while reed beds form a distinct localities for birds.

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### Biographical Sketches

**Dr. Tilak Priyadarshana** is a Senior Lecturer at the Department of Fisheries Biology, University of Ruhuna, Sri Lanka. Before the current position he worked as a researcher at the Department of Environmental Sciences and Human Engineering, Saitama University, Japan for two years. He graduated from the University of Ruhuna in Sri Lanka and afterwards he continued his research for a Ph.D. at the Department of Civil and Environmental Engineering at Saitama University, Japan. His major interests include community ecology with major emphasis on aquatic ecosystems and how major ecological processes, such as competition (i.e., bottom-up forces), predation (i.e., top-down forces), and keystone species (i.e., intermediate, strong regulators, often in the middle of the food web) structure freshwater communities and in turn how these findings can be utilized to manage aquatic ecosystems. He is the author of several research publications on ecological restoration of lakes and reservoirs.

**Dr. Takashi Asaeda** is the head, Department of Environmental Sciences and Human Engineering, Saitama University, Japan. He graduated from Tokyo University in 1976 and obtained his Ph.D. from the Department of Civil Engineering at the same university in 1983. He has received many awards during the course of his career. At the University of Tokyo he received the Karl Emil Hydraulic Prize (ASCE) in 1983 and APD-IAHR Award for outstanding performance in 1986. In 1999, the Dam Engineering Society awarded him with the Best Engineer Award. He was appointed as an associate professor of Civil Engineering at Tokyo University and served from 1984 to 1989. He joined Saitama University, in 1989, was promoted to a professor in 1999. His current research includes aquatic environmental engineering with special emphasis on ecology of aquatic ecosystems. Currently, he is the editor of several books and international journals as well as participating actively in many governmental committees. From 1983 he has published his research and findings in more than fifty articles in various international journals.

**Dr. Jagath Manatunge** is a research associate at the Department of Environmental Science and Human Engineering, Saitama University, Japan. Early training in civil and environmental engineering at the

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