

Chapter 3

Ecosystems Services of Rivers and their Relation to Flows

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Humans have depended upon ecosystems for all their needs, ever since they hunted and gathered food and used the water from the rivers. As they began to grow their food, they took advantage of the natural renewal of soil fertility by the annual spilling over of river waters into the floodplains every year. The physical and biological features of different ecosystems inspired and contributed to cultural and spiritual development. Gradually, humans learnt how to exploit, control and manipulate different ecosystems to their advantage. The impact of human activities and their consequences for humans themselves became apparent long before we gained insights into the organisation and interactions between different constituents and overall functioning of ecosystems at different scales. Attention was drawn to the rapid deterioration of various ecosystems (Marsh 1864), but humans did not realise the threat to themselves, as local communities did not identify themselves as part of a larger global ecosystem.

After environmental degradation assumed serious proportions and its global ramifications became clear (e.g., Carson 1962), efforts were initiated to awaken people to their dependence on the natural environment, and to mitigate environmental problems (e.g. the United Nation's Conference on Environment, Stockholm, 1972). At the same time a utilitarian view of nature was put forward to increase people's interest through the notion of 'nature's services' or 'environmental services' (SCEP 1970) (albeit it seems to suggest that nature is subservient to humans). Later, Ehrlich and Ehrlich (1981) introduced the term 'ecosystem services' which received wide acceptance after Daily (1997) promoted

the concept by defining it as “the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfill human life”. The concept was elaborated by Scott et al. (1998) who explained that whereas the ecosystem (or ecological) processes are “interactions among elements of the ecosystem”, and ecosystem functions are “aspects of the processes that affect humans or key aspects of the ecosystem itself...”, ecosystem services are “attributes of ecological functions that are valued by humans”. De Groot et al. (2002) defined functions as “the capacity of natural processes and components to provide goods and services that satisfy human needs”. In other words, ecosystem processes lead to functions, which in turn lead to services. These terms are discussed further by Wallace (2007).

According to Edwards and Abivardi (1998), “the formulation of the concept of ecosystem services was a deliberate attempt to draw ecological processes into the domain of economics. As long as the supply of these services was more than ample, there was no need to consider them in economic terms, and for this reason economic activity often caused them to be significantly degraded (Freedman 1995). An important step in sustaining these conventionally non-valuated resources is, therefore, to define them as goods and services which can be quantified in economic terms.”

The concept of ecosystem services received a big boost from the Millennium Ecosystem Assessment (MEA 2005) which defined them simply as “the direct and indirect benefits derived by humans from the functions of the ecosystems”. The Millennium Ecosystem Assessment focused specially on direct and indirect linkages between ecosystem services and human well being (including poverty alleviation) (Figure 1). The MEA examined in detail the changes that have occurred in different kinds of ecosystems and their services over the past 50 years, their causes and consequences for human well-being, and the trends of changes into the future. The Millennium Ecosystem Assessment also examined the options for enhancing the conservation of ecosystems and their contribution to human well-being.

The Millennium Ecosystem Assessment (2005) grouped various ecosystem services into four major categories: Provisioning, Regulating, Cultural and Supporting services. In brief, provisioning services provide the material benefits (often called goods) that are directly consumed or used by humans, while regulating services provide indirect benefits through the regulation of environmental media or processes. Cultural services are non-material benefits derived by humans in fulfilling their cultural and spiritual needs. Supporting services are required to sustain the ability of the ecosystems to deliver the other three services over long periods. It is important to realise that various ecosystem services are interrelated and cannot be considered in isolation. The same set of biotic and abiotic processes result in many functions which are valued by humans differently. The four kinds of ecosystem services are elaborated below following the MEA approach.

Provisioning Services

Humans obtain a very wide range of goods of which food (products derived from plants, animals, and microbes), fiber (such as wood, bamboo, grass, jute, cotton, hemp, silk and wool), fuel (wood, dung, etc.) and biochemicals and natural medicines (plant or animal

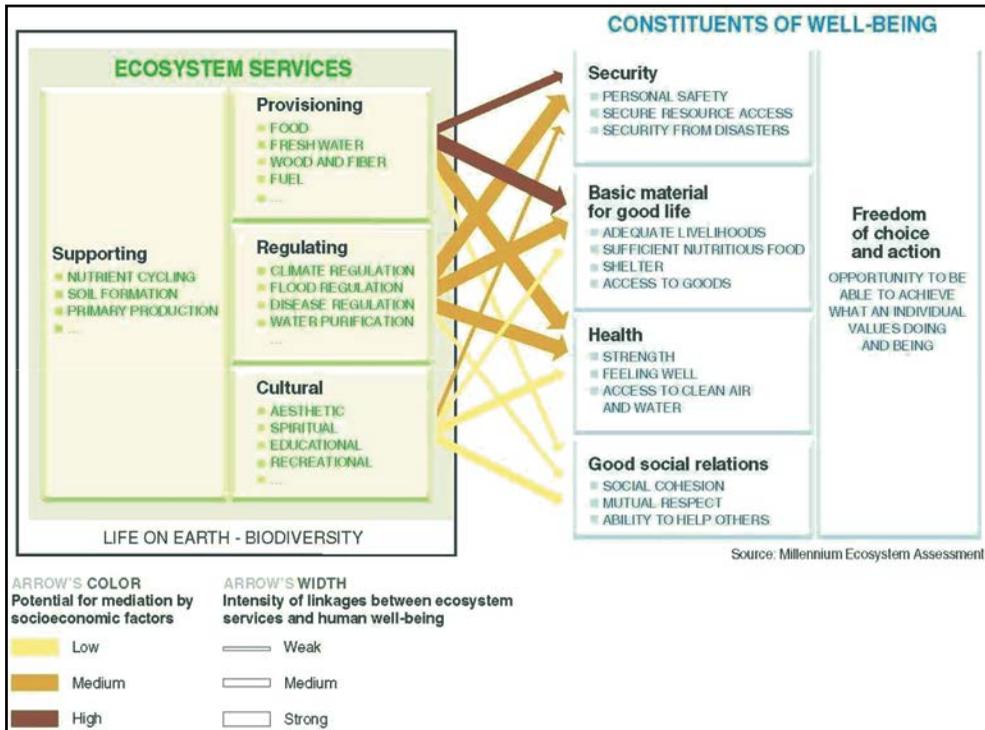


Figure 1. Various ecosystem services and their relationship with human well-being (from MEA 2005)

origin, biocides, essential oils, food additives, etc.) are of every day interest. Animal and plant products, such as skins, shells, and flowers, used for ornamental purpose and whole plants used for landscaping and ornaments are also provisioning services. Further, the ecosystems provide genetic resources (e.g., genes) which are used for animal and plant breeding and biotechnology. Inasmuch as the supply of fresh water depends upon the ecosystem processes, it is also considered a Provisioning service. Water in rivers is also a source of energy.

Regulating Services

Several ecosystem processes regulate other processes and components in a manner that benefits humans indirectly. For example, ecosystems regulate air quality by both, contributing chemicals (e.g., methane, nitrous oxide, H₂S, aerosols) to and extracting them from the atmosphere. Ecosystems regulate both local (microclimate) and global climate by influencing temperature and precipitation regimes and by either sequestering or emitting greenhouse gases (chiefly carbon dioxide and methane).

The water cycle is regulated by influencing the timing and magnitude of runoff, flooding, and aquifer recharge. Vegetation helps retain soil (trapping and binding among roots) as well as prevents landslides, and thereby regulates erosion. In coastal areas, mangrove ecosystems are known to reduce the damage caused by natural hazards such as

cyclonic storms and tsunami waves. Another service of great interest is the regulation of water quality as the ecosystems help remove organic and other contaminants from soils and water, but may sometimes be also a source of impurities in fresh water. Another regulating service is the regulation of diseases as ecosystems affect the abundance of human pathogens as well as the abundance of disease vectors (e.g., snails, mosquitoes). Pests and diseases of crops and livestock are regulated by ecosystems through better conditions for their growth and multiplication or by harbouring their predators. Ecosystems regulate pollination by influencing the distribution and abundance pollinator organisms.

Cultural Services

Cultural and spiritual activities have their origins in the close association of humans with natural ecosystems. The large cultural diversity in different parts of the world is a direct reflection of the diversity of ecosystems. Art and literature have been always inspired by natural systems and various forms of recreational and leisure activities directly depend upon the characteristics of natural ecosystems. Over the past many millennia, much of human knowledge came from their interaction with and observations of the processes and functions of natural systems. This knowledge, called as traditional knowledge as distinguished from the present formal knowledge system, is now being increasingly valued. Although humans gradually drifted away from nature and started altering, and even destroying natural ecosystems drastically, they continue to seek peace and comfort in the lap of natural ecosystems, and often try to create situations that mimic nature. Thus, humans derive from the ecosystems innumerable nonmaterial, non-quantifiable, benefits which include spiritual, recreational, aesthetic, social, educational and inspirational experiences.

Supporting Services

The ability of ecosystems to provide the numerous above mentioned services, is supported by certain long-term processes and functions. For example, soil is necessary for the growth of most of the vegetation, but its formation involves many physical, chemical and biological processes over centuries. Therefore, soil formation is considered as a supporting service that indirectly benefits humans. Similarly, the cycles of water and nutrients are also supporting services.

During the past few years, many studies have discussed the ambiguities and limitations of the MEA categorisation, especially from the viewpoint of valuation (Haines-Young and Potschin 2009). Several variants of classification schemes for ecosystem services have been proposed (DeGroot et al. 2002, Wallace 2007, 2008, Fisher and Turner 2008, Fisher et al. 2009) while the main framework remains the same. Costanza (2008) has even pointed out the need for multiple classification schemes. Currently, a Common International Classification of Ecosystem Services (CICES) is being developed ‘as part of the revision of the System of Environmental-Economic Accounting’ with support from the European Environment Agency (Haines-Young and Potschin 2011, 2013) that is now in its 4th version. This is a hierarchical system which recognises only three main categories called ‘Sections’ – Provisioning, Regulating and Cultural – which are divided into ‘Divisions’ and subdivided

into ‘Groups’ (Table 1). It also makes a distinction between environmental goods and services and ecosystem services. The term ecosystem services describes various flows (e.g. extracted natural resources, pollination by bees, soil formation) within the environment and from the environment to the economy and society. In contrast, environmental goods and services comprise only of flows of products within the economy.

Table 1. Proposed structure of CICES V4 made by EEA (from Haines-Young and Potschin 2013)

Section	Division	Group
Provisioning	Water	Water
	Materials	Uncultivated terrestrial plants and animals for food
		Uncultivated freshwater plants and animals for food
		Uncultivated marine plants, algae and animals for food
		Nutrients and natural feed for cultivated biological resources
		Plant and animal fibres and structures
		Chemicals from plants and animals
		Genetic materials
	Energy	Biomass based energy
	Other provisioning services	Other provisioning services, n.e.c.
Regulating	Remediation and regulation of biophysical environment	Bioremediation
		Dilution, filtration and sequestration of pollutants
	Flow regulation	Air flow regulation
		Water flow regulation
		Mass flow regulation
	Regulation of physico-chemical environment	Atmospheric regulation
		Water cycle regulation
		Pedogenesis and soil cycle regulation
		Noise regulation
	Regulation of biotic environment	Lifecycle maintenance, habitat and gene pool protection
Pest and disease control (incl. invasive alien species)		
Cultural	Physical or experiential use of ecosystems [environmental setting]	Non-extractive recreation
		Information and knowledge
	Intellectual representations of ecosystems [of environmental settings]	Spiritual & symbolic
		Non-use

ECOSYSTEM SERVICES OF RIVERS

The foregoing discourse on ecosystem services is not necessary to appreciate the services of rivers to humankind. Humans have depended upon the rivers for the provisioning of water and fish since ages. Humans have also known the role of rivers in the assimilation of organic wastes and in the renewal of fertility of floodplains. A recognition of these services is implicit in the fact that throughout the Indian subcontinent, and in many other regions of the world, rivers are revered as a 'mother', and are often also worshipped as goddesses.

Ecosystem services of rivers in the current conceptual framework have been examined in relatively few studies (e.g., Straton and Zander 2009; Table 2) although floodplain wetlands have received considerable attention. The assessment of riverine ecosystem services is somewhat complex because of several reasons. First, they differ from terrestrial ecosystems in their biotic and abiotic components and in their temporal dynamics. Second, rivers vary in the hydrogeomorphic features from their source to the mouth and are influenced by tributaries (Rice et al. 2008) and their basin characteristics. As discussed in the earlier chapter, sections of the river entrenched in deep narrow and steep valleys differ from those in the plains, where they may meander or form braided or anastomosing channels, and may have narrow or wide alluvial floodplains. Thorp et al. (2010) recently examined the relationship between ecosystem services and hydrogeomorphic features, which differ greatly in different stretches (identified as Function Process Zones) of the river (Table 3). However, it is important to note that the floodplains do not exist in isolation of the river channels, and the downstream hydrogeomorphic patches depend upon the flows and sediments from upstream areas. Further, ecosystem services also vary in their nature and magnitude at different spatial scales (Hein et al. 2006). For example, ecosystem services of small rivers such as those of the Western Ghats in India, or in Sri Lanka, Malaysia or Indonesia, would differ greatly from those of large rivers like the Ganga, Brahmaputra and Mekong.

Ecosystem services further depend upon the ecological integrity of the system, which is ensured only by longitudinal, lateral and vertical connectivity within the system, and between adjoining systems. Thus, ecosystem services of a river system vary greatly in its different reaches with the changes in their structural components (channel morphology, sediments, biota, flow regimes and water quality). The total ecosystem services of an entire river ecosystem on a basin scale are indeed difficult to assess and such an assessment has rarely been attempted (see DeGroot et al. 2008, Batker et al. 2010, Zander and Straton 2010, Kaval 2011). Main ecosystem services of rivers in general are briefly described below following the MEA framework.

Provisioning Services

Water is considered to be the most important provisioning service of the rivers. However, the rivers do not produce water. They collect it from their catchment areas and on their way to the oceans, make it available to humans. Provisioning of groundwater through infiltration in alluvial floodplains is another important service. Water in high gradient streams is also a potential source of energy.

Table 2. Ecosystem services of Australia’s tropical river systems and examples of the activities and benefits they provide (from Straton and Zander 2009)

Ecosystem services	Examples of goods, activities and benefits provided
<i>Provisioning</i>	
Food	Production of fish, other aquatic and terrestrial species, fruit, and grains for recreational and subsistence hunting and gathering
Fresh water	Storage and retention of water for domestic, ecological, aquaculture, mining, fishing, and agricultural use
Fibre and fuel	Production of logs, fuelwood, and fodder for building, cooking, and warmth
Biochemical	Production of biochemicals and medicines
Genetic materials	Production of genetic material
<i>Regulating</i>	
Climate regulation	Source of and sink for greenhouse gases; influence local and regional temperature, precipitation, and other climatic processes
Water regulation (hydrological flows)	Groundwater recharge/discharge; hydrological regime is key driver of ecosystem processes and food-web structure
Water purification and waste treatment	Retention, recovery, and removal of excess nutrients and other pollutants
Erosion regulation	Retention of soils and sediments
Natural hazard regulation	Flood control, storm protection
Biological control	Control of pests and diseases
<i>Cultural</i>	
Spiritual and inspirational	Source of inspiration for well-being and art; spiritual benefit; specific and unique indigenous spiritual and cultural values
Recreational	Opportunities for recreational activities and tourism
Heritage and sense of place	Cultural heritage and identity
Aesthetic	Many people find beauty or aesthetic value in aspects of wetland ecosystems
Educational	Opportunities for formal and informal education and training
<i>Supporting</i>	
Soil formation	Sediment retention and accumulation of organic matter
Habitat provision	Provision of habitat for wildlife feeding, shelter, and reproduction
Nutrient cycling	Storage, recycling, processing, and acquisition of nutrients

Table 3. Relationship of ecosystem services of different kinds of rivers to their hydrogeomorphic attributes (adapted from Thorp et al. 2010).

Ecosystem services and benefits	Constricted + Straight	Meandering	Braided	Anastomosing +Anabranching	Leveed	Reservoir
Hydrogeomorphic attributes						
Sinuosity (shoreline length to downstream length ratio)	•	••	●	●	•	•
Relative number of channels	•	•	●	●•	•	•
Functional habitats within channels	•	••	•	●	•	••
Permanence of channel/islands	•	•	•	●	•	●
Floodplain size and connectivity with main channel	•	••	•	●	•	•
Natural ecosystem services						
Species richness and trophic diversity	•	•	•	●	•	•
Proportion of native biota	●	●	●	●	•	•
Primary and secondary productivity	•	•	•	●	•	•
Nutrient cycling and carbon sequestration	•	••	••	●	•	●
Water storage	•	••	•	●	•	●
Sediment storage	•	•	•	●	•	●
Anthropocentric services						
Food and fiber production (excluding agricultural production)	•	•	•	●	•	•
Potential for water abstraction	••	•	•	•	●	●
Recreation	••	••	•	●	•	●
Disturbance and natural hazard mitigation	•	•	•	●	●	●
Transportation/ navigation	●	•	•	•	●	●

The hydrogeomorphic attributes and ecosystem services are noted at three levels: • Low; ● Medium and ● High

Fish (including shrimp and prawn) are a major provisioning service that depends upon the provisioning of food in the form of primary and secondary production in the river channel. Even coastal fisheries which depend upon freshwater flows from rivers, should also be considered as part of the rivers' provisioning services (Bunn et al. 1998).

Rivers further provide, through annual flooding of the floodplains, a variety of plant resources which are used as food, fuel, timber, fiber and forage.

Regulating Services

One of the most important ecosystem services of rivers is the hydrological regulation. Floodplains help moderate flooding and help recharge ground waters (Acreman et al. 2003, Burt 1997, Fujii et al. 2003). While some of the flood water held in the floodplain infiltrates into the ground, and some is gradually released back into the river. Babu et al. (2001) and Kumar (2004) have estimated the groundwater recharge function of floodplains of River Yamuna at Delhi and also assessed its economic value. Associated with groundwater recharge is another regulating service - the improvement of water quality as nutrients and pollutants are removed by various processes while passing through soil layers. However, excessive pollution loads (organic matter and nutrients) in the river may result in groundwater pollution as well, if the bed sediments are permeable.

Next very important ecosystem service is their capacity to assimilate organic wastes. This is based on many processes involving biogeochemical transformations in different habitats – within the water column, on the river bed, in the hyporheic zone, riparian zone and most significantly in the floodplains. Some organic wastes are also removed by direct consumption by certain aquatic fauna (fish, prawn, turtle, gharial). Hyporheic resident fauna also helps reduce pollutants (Stubbington 2012, Gandy et al. 2007; Domagalski et al. 2008). Flow regimes play an important role in this function through downstream transport (nutrient spiraling), dilution, oxygen supply to the decomposer organisms, ensuring surface water-groundwater interactions and the river-floodplain interaction. Aquatic and wetland plants play a critical role in sequestering nutrients as well as many other pollutants. Forested floodplain buffers prevent nonpoint source pollutants from entering small streams and enhance in-stream processing of both nonpoint and point source pollutants (Lowrance et al. 1984, Sweeney et al. 2004). Reduction or lack of flow and degradation of habitats (particularly the loss of floodplains) have the most severe impact on this ecosystem service, with several other consequences for biota and humans.

Another regulating service of considerable interest is the climate regulation (through carbon sequestration in floodplain wetlands and forests (such as those of the river Amazon). The protection against tropical storms offered by the mangroves may also be considered as a regulating service of the rivers because the sediments and freshwater carried by them are crucial to the sustenance of the mangroves (see Gopal 2013).

Cultural Services

The 'cultural services' of rivers in South Asia clearly distinguish them from rivers elsewhere in the world. Many social, cultural and religious activities have been tied inextricably to the

rivers since ages. Activities such as sport fishing, swimming, rafting, and recreational boating are common throughout the world though, their importance varies greatly between cultures. In South Asia, religious activities such as mass bathing and placing offerings in rivers are associated with the reverence for rivers as goddesses. Mass bathing that occurs on specific auspicious days provides an opportunity for social gathering and communication. A cultural activity associated with the rivers has been the cremation of dead bodies on river banks and disposal of ashes into the flowing water (usually in the middle of the river). Another religious activity is the submersion of idols and religious offerings (flowers, leaves, etc.) into the rivers, following certain holy festivals. These activities caused no perceptible degradation of the river as long as flows were not regulated, and the natural riverine biodiversity helped assimilate these ‘wastes’ as described above. In the context of cultural services, it is important to recognise the difference in the perception of different communities even within a region. For example, in northern Australia, the aboriginals attach greater value to the river in their daily spiritual lives and to dry season water holes for their customary activities, than other people (Straton and Zander 2009, Zander and Straton 2010).

Mention must be made here of the numerous river system-based livelihoods of local communities, besides of fisherfolk. Navigation by country boats, extraction of sand and gravel, and plant resources from the floodplain support numerous people. Some communities are also engaged mainly in supporting rituals and associated material needs of religious and cultural activities. Needless to say that these activities and livelihoods depend entirely upon the river flows.

Supporting Services

Rivers support soil formation by transporting minerals (sand/gravel) and converting them to different grain size material for habitat support to the riverine biota, besides human use. The organic matter and nutrients carried with the sediments supports rejuvenation of fertility of the floodplains.

Human derive some indirect benefits as well from the rivers which are utilised for transport. River-based transport systems lowers energy demands and saves on infrastructural costs, while the flow in the river continues to provide other ecosystem services.

Biodiversity and Ecosystem Services

Ecosystem services are closely linked to the biodiversity of the ecosystem (Ehrlich 1995, Mooney et al. 1996). In rivers as well, biodiversity plays a major role in their ecosystem services. The invertebrates process the organic matter and support the fisheries. The hyporeheic fauna contributes to secondary production (Smock et al. 1992, Wright-Stow et al. 2006) and water quality improvement. Fish also regulate other ecosystem services through their feeding and other behavioural activity (Holmlund and Hammer 1999). Fish also contribute to recreational services, as angling is a major recreational activity in many countries. Higher biodiversity in the riparian areas and floodplains is also accompanied with greater ecosystem services as discussed above.

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