Restoring Riparian Ecosystems During the UN-Decade on Ecosystem Restoration: A Global Perspective

**Maresh Mohan¹ · Ashly Chacko¹ · Mutharimettak Rameshan¹ ·
Velamparambil Gopalakrishnan Gopikrishna¹ · Vatharamattathil Mohanan Kannan¹ ·
Nalinakshan Geetha Vishnu¹ · Sasi Arun Sasi¹ · Kalathilparambil Rajappan Baiju¹**

Received: 19 September 2021 / Revised: 4 February 2022 / Accepted: 7 February 2022 / Published online: 24 February 2022
© The Author(s), under exclusive license to Springer Nature Singapore Pte Ltd. 2022

Abstract

Ecosystems across the globe, be it terrestrial, marine or transitional in nature are under pressure due to multiple drivers of changes including anthropogenic. Restoring the vitality of degraded systems is crucial for fulfilling the UN-Sustainable Development Goals in a timely manner. It is also essential for attaining the targets of the ambitious UN-Decade on Ecosystem Restoration (UN-DEER). Riparian ecosystems are one among systems undergoing drastic changes due to anthropogenic pressures. They are a heterogeneous and biodiversity rich system due to its transitional zone occurrence between terrestrial and aquatic realms, including riverbanks, floodplains and wetlands, and provide ecosystem services on both local as well as global levels. Here we review the prospects of restoring riparian ecosystems in the context of the UN-DEER. Even though the momentum for restoring riparian habitats began in the 1970s, our study reveals that intensive restoration programmes across the world are sparse and more efforts are needed to restore degraded riparian systems for regaining ecosystem health and complexity. Furthermore, an in-depth analysis of various strategies deployed for restoring riparian ecosystems around the world reveals that a participatory approach and site-specific strategies are needed for better output. Also, active along with passive restoration is required for better recovery. We suggest a three-stage strategy—preassessment, restoration activities and post monitoring and maintenance. It includes the involvement of stakeholders across all stages, which also supports their livelihoods. The restoration of riparian ecosystems supports the targets of UN-DEER while providing both global as well as local ecosystem services.

Keywords River · Forest · Degradation · Stakeholders · Ecosystem · Restoration

1 Introduction

Ecosystems support various life forms on earth. Down the ages, human activities have impaired ecosystems around the world (Dybala et al. 2018; Lewis et al. 2019; Álvarez-Yépiz 2020). The acreage of pristine ecosystems is decreasing across the planet and is on the verge of degradation (Lengyel et al. 2020). Restoration of ecosystems is required for the survival of all organisms (Vollmer et al. 2015; Daigneault et al. 2017; Mohan et al. 2020). Restoration is the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed (SER (Society

for Ecological Restoration), 2004). From an ecological perspective, it is an intentional activity that reinstates ecological processes that were interrupted when an ecosystem was impaired (Chazdon et al. 2021). Restoration can be passive as well as active. Passive restoration involves halting all activities such as land-use changes that can affect the ecosystem, and preserving the region in such a manner that all endurers and resistors can grow naturally (Kauffman et al. 1995). Active restoration, on the other hand, involves the introduction of plants and supporting their growth externally. Passive restoration efforts can take time to restore a natural ecosystem, while active restoration with human intervention can accelerate and influence ecosystem recovery (Holl and Aide 2011). Highly disturbed areas can be revived through active restoration where regeneration is possible; while less degraded regions can be revitalised through passive restoration (Álvarez-Yépiz 2020). Eco-restoration

✉ Mahesh Mohan
maheshmohan@mgu.ac.in

¹ School of Environmental Sciences, Mahatma Gandhi University, Kottayam 686560, Kerala, India

ensures environmental security as well as the socio-economic well-being of rural communities (UNEP 2019; CBD 2019). Sustainable and effective implementation of restoration efforts can enhance ecosystem services and also support climate change mitigation, resilience and adaptation (Gann et al. 2019).

For the last three decades, more emphasis has been given to restoration activities worldwide (Verdone and Seidl 2017; Stanturf et al. 2019). The Bonn Challenge is one among them, whose goal was to restore 150 million ha of degraded landscapes by 2020 and 300 million ha by 2030 (Verdone and Seidl 2017; Dave et al. 2018). In 2017, The New York Declaration on Forests called for a timeline to halve our natural forest loss by 2020, and strive to end it by 2030 (zu Ermgassen et al. 2020). The Declaration also called for restoring large areas of forests and croplands. Such conservation and restoration activities indicate a positive response (Curtis et al. 2018). The report on the State of the World's Forests indicates a positive change in our net forest area (FAO 2020). Among the various activities that influenced the net change in forest area, active restoration efforts have seen an increase during the last decade over the 2000–2010 period, when regeneration was a major activity (FAO 2020). The success of past restoration activities has paved the way for UN-DER. It aims to prevent, halt and reverse the degradation of ecosystems around the world (Abhilash 2021).

Among the various ecosystems, riparian regions cover only 0.5–1% of the global land area (Hawkins 1994; Sutfin et al. 2016). However, riparian ecosystems enjoy high ecosystem values and support the livelihood of large populations around the world. They possess a rich diversity and various ecosystem functions (Riis et al. 2020) while accounting for 0.5–8% of global soil organic carbon (SOC) storage (Dybala et al. 2018). Riparian restoration has been conducted worldwide (Kauffman et al. 1995; Rood et al. 2003; Shafroth et al. 2008; White and Stromberg 2011; Gumiero et al. 2013; Gonzalez et al. 2015). It started from the early 1970s with studies on riparian ecosystems and restoration practices increasing from time to time (Hawkins, 1994; Goodwin et al. 1997; González et al., 2015). Till 1995, in fact, more than 400 studies had been published only on riparian restoration in the western USA (Goodwin et al. 1997).

2 Riparian Ecosystems

Riparian ecosystems serve as buffer zones between aquatic and terrestrial ecosystems (Richardson et al. 2007). These are crucial transition zones that allow materials and energy to flow from one ecosystem to another (Ewel et al. 2001). Riparian forests also act as wildlife corridors, while supporting the filtration of pollutants and improving hydrology. Riparian zones contain much greater biomass of total

plant material than non-forested vegetation (both deciduous and coniferous) (Gregory et al. 1991). These ecosystems usually occur on the floodplains and near the top of stream banks, on stream bank faces, and within the channel on point bars, alternate bars, and mid-channel bars. Riparian vegetation closer to the active channel is characterised by younger stands, mainly composed of deciduous shrubs and trees. Riparian forest areas, which are a major part of riparian ecosystems, are more prevalent along lower order streams (upper reaches of a river) than along higher-order streams (lower reaches of a river). Types of riparian systems differ with respect to their altitude. At higher altitudes, grasslands and narrow strips of forests with stunted trees occur along the river banks. However, at the lower reaches of a river, the width of riparian ecosystems varies widely. The width of a riparian system is typically based on its size and position within the drainage network, the hydrology and the local geomorphology (Naiman et al. 1993).

Plant life of riparian ecosystems is highly efficient against frequent water level fluctuations and can be withstanding such hydrological changes. These plants are adapted to the flooding, sediment deposition, physical abrasion, and stem breakage with suitable physiological modifications (Naiman et al. 1998). However, their susceptibility to flooding varies. The severity of flooding in a riparian zone influences the spatial pattern of species composition (Bendix 1999). Riparian vegetation is, thus, ecologically different from the adjacent terrestrial vegetation (Richardson et al. 2007). They are distinguished by a wide range of aquatic and terrestrial habitats that are supported by fluvial processes (Tockner and Ward 1999). High plant diversity is observed in riparian zones (Handcock et al. 1996; Olson et al. 2007). Apart from plant diversity, faunal diversity is also high among riparian ecosystems (Ribeiro et al. 2012; Vasconcellos et al. 2013; Jiménez-Carmona et al. 2020; Chen et al. 2021).

Riparian ecosystems today face a serious threat from various development activities around the world (Capon et al. 2013; Arsenio et al. 2020). It is time to restore them since they support unique biodiversity and since their restoration will help in attaining the UN Sustainable Development Goals (SDGs) (Basak et al. 2021). It will have a global significance in terms of increasing biodiversity and carbon sequestration, improvement in the weather, hydrology, etc. (Feng et al. 2013; Lewis et al. 2019; Zhao et al. 2021). However, it is important to understand the functions of riparian ecosystems, successful approaches for their restoration, and limitations for better implementation of the riparian ecosystem restoration (RER) around the world. Hence, this present review aims to clarify the different functions and importance of riparian ecosystems. It evaluates the various threats to the riparian ecosystem as well as the various restoration approaches. The review assesses various methods used for the evaluation of the success, benefits, and limitations of

2.1 Various Functions of Riparian Ecosystems

The riparian ecosystem serves as a linear ecological corridor for a range of species, from lower aquatic types to large herbivores such as elephants, since rivers pass through multiple habitats (Johnsingh et al. 1990; Basak et al. 2021). Most of the elephant corridors and linking ties between different habitats in the Western Ghats of India are aligned

Riparian plants influence rainfall, temperature and humidity while cooling the waterbodies by providing shade, controlling the flow velocity and flooding, and providing microhabitats for aquatic organisms like fish (Kaylor and Warren 2017). There is considerable variation in riparian species diversity, density and richness with high endemism based on the landscape of the riparian vegetation (Kennedy et al. 2002). It influences riverbank erosion, mineral accumulation, hydrocarbon reservoirs and aquifers, hydrology, and soil erosion, which can finally offer equilibrium and stability

Fig. 1 Functions of riparian ecosystems

to rivers and river banks (Coulthard 2005; Bolla Pittaluga et al., 2003). Riparian forests can act as refugia of forest species from nearby regions (Meave et al. 1991). In a changing environment, riparian regions serve as havens for conserving such species, despite their low density (Meave et al. 1991; Naiman et al. 1992). The capacity of accumulating carbon in the riparian ecosystem is a significant factor in terrestrial carbon cycling, which regulates carbon transport to oceans (Sutfin et al. 2016; Dybala et al. 2018), hence influencing global climate change (Seavy et al. 2009; Capon et al. 2013). According to Sutfin et al. (2016), major organic carbon reservoirs in riparian ecosystems are: (a) above-ground biomass, (b) deadwood biomass, and (c) organic carbon (OC) on and beneath the surface.

Since time immemorial, riparian landscapes have influenced the traditional culture, economic and political life of forest-dwelling local indigenous communities (Celentano et al. 2014; Mohan et al. 2020). The wild, non-cultivated, and non-domesticated plants and animal species from riparian ecosystems provide an important hidden harvest for the livelihoods and sustenance of natural forest dwellers and rural communities (Klapproth and Johnson, 2009; Oestricher et al. 2014; Richardson 2012). Forest-dwelling indigenous communities are supported with food, medicine, firewood, etc., from these ecosystems; for example Chacales used in Western Mexican riparian regions (Flores-Díaz et al. 2014); mammals, avian and aquatic fauna used in lowland riparian areas of Venezuelan Guayana (Huber and Zent

1995); and medicinal plants used in the Brazilian Amazon (Pedrollo et al. 2016; Ferreira Rodrigues Sarquis et al. 2019). Indigenous riparian communities have an inseparable connection with the natural resources gathered from their local ecosystems, which play a vital role in the communities' economic and social growth (Celentano et al. 2014; Nagaraja et al. 2014; Mul et al. 2018).

2.2 Threats to the Riparian Ecosystem

The regions of riparian vegetation are flooded with seasonal water flow. The threats on riparian systems can be natural or human-induced (Fig. 2) (Goodwin et al. 1997; Bendix and Hupp, 2000; Nilsson and Berggren, 2000; Iwata et al. 2003; Richardson et al. 2007; Cornejo-Denman et al. 2018). Riparian systems are impacted by natural disturbances once in 50 years due to landslides and floods (Richardson et al. 2007). However, anthropogenic disturbances such as dams reduce the flow and sediment load prevent the expansion of riparian ecosystems, especially those associated with braid bars or sand bars. Rood et al. (2003) observed a reduction in the formation of new landforms as pioneer vegetation has no more room to grow. Recently, climate change has started affecting most ecosystems around the world. Climate change-induced disasters like incessant rainfall, large landslides, flash floods, etc., have adversely affected riparian ecosystems along the banks and braid bars of rivers (Perry et al. 2015). Saritha et al. (2019) observed a loss of more

Fig. 2 Various threats on riparian ecosystems

than 50% of riparian forest, which is associated with braid bars in the Chalakudy river of Western Ghats due to the 2018 flood in Kerala. Flores et al. (2021) indicated the effect of large savanna wildfires on tropical riparian forests. They observed a drop in canopy cover from 90 to 20% after the wildfire in 2017.

The increasing rate of fragmentation along wildlife corridors has serious impacts on the survival of many species due to their isolation, local abundance, and inbreeding (Rameshan et al. 2014; FAO 2020). Adopting measures such as the identification of gaps along the riparian corridors and establishing linkages between the riparian ecosystems through restoration is necessary to retain the ecological integrity of the landscape and biodiversity conservation. Another threat to the riparian ecosystem is roads and construction activities. Most roads are constructed parallel to rivers. This causes waste dumping, disturbances for vegetation, and construction activities in the riparian region (Adams and Ringer 1994; NRC 2002). Also, it can affect water percolation and quality. The distribution of invasive species in riparian areas is also enhanced by roads (Menuz and Kettenring 2013). Uncontrolled ecotourism is a threat to riparian ecosystems, causing more waste accumulation in riparian areas (Cowger et al. 2019).

3 Restoration of Riparian Ecosystems

The restoration of the riparian ecosystem is inevitable as significant changes occurred in its structure and functions due to human interferences (Wissmar, 1998). The riparian eco-restoration is more critical than other eco-restoration ventures and is instrumental in the conservation and recovery of aquatic and terrestrial biodiversity habitats (Fremier et al. 2015; Arsenio et al. 2020; Basak et al. 2021). The restoration of riparian ecosystems is globally significant as it supports large human populations, biodiversity, and critical ecosystem services (Daigneault et al. 2017). On a global scale, biodiversity-rich riparian ecosystems are culturally rich and managed or co-managed by the various forest-dwelling local indigenous communities (Phillips 1998; Verry et al. 2004; Voggeser 2006). Apart from reducing environmental impacts, riparian eco-restoration helps to improve the eco-cultural restoration of diverse forest-dwelling indigenous communities around the globe (Long et al. 2003; Voggeser 2006; Kimmerer 2011; Vollmer et al. 2015; Stevens 2020).

The restoration of the riparian ecosystem is vital as it can store a large quantity of recalcitrant carbon (Sutfin et al. 2016). They are highly resilient in nature (Capon et al. 2013). Riparian ecosystems connect various habitats linearly, link aquatic and terrestrial ecosystems, and function as thermal and wildlife refugia (Meave et al. 1991; Seavy et al. 2009; Mohan et al. 2020). These characters can contribute to

the ecological adaptation of riparian ecosystems to climate change adaptation (Seavy et al. 2009; Capon et al. 2013). Not all restoration activities are successful, and the success of restoration is depending on the identified problems, subsequent planning and participation of stakeholders. For example, the presence or absence of invasive species or the time and mode of introduction of invasive species may influence the restoration activities (Richardson et al. 2007). It is indicated that proper planning is inevitable for a successful restoration. Additionally, the socio and ecological context remain the key to a successful restoration programme (Arsenio et al. 2020).

The successful planning of restoration requires an understanding of hydrogeomorphic processes and biotic change, processes that create and maintain riparian ecosystems (Goodwin et al. 1997). The past channel changes and details of activities that influence sedimentation and flow, such as deforestation and damming, should be studied for effective planning (Kondolf and Larson 1995; Stromberg 2001). The engineering approaches for riparian restoration focus on in-channel modifications with little consideration for the interactions between stream channel and riparian vegetation. In most cases, artificial revegetation and engineering in the restoration of riparian ecosystems are ineffective (Kauffman et al. 1995). Hence, the ecological approach, where the applied practices aim at facilitating recovery, otherwise known as eco-restoration, is preferred for riparian restoration. It has been recognised right from the very early stages of the history of riparian restoration (Kauffman et al. 1995). There are many strategies for restoring riparian ecosystems. Gonzalez et al. (2015) reviewed various categories of projects based on the strategies of restoration around the globe. These are hydro-geomorphic in nature, including steps such as active plant introduction, exotic species control, conversion to a natural floodplain, grazing and herbivory control, water quality improvement and soil remediation, etc. Table 1 shows various strategies followed across locations for the restoration of riparian ecosystems. These strategies also use specific steps and processes for these restoration projects.

3.1 Steps and Processes for RER

The riparian restoration consists of three phases such as pre-assessment, restoration, and post monitoring and maintenance (Fig. 3) (Bigley and Deisenhofer 2006; Shafroth et al. 2008; Withrow-Robinson et al. 2011; Mohan et al. 2020). These are general steps for riparian restoration. However, the steps can be modified as per the type of restoration programme. For example, Shafroth et al. (2008) discussed a seven-step process for removing invasive species and restoring a region. The pre-assessment phase will determine the major source of disturbance and its impacts. The major direct and indirect impacts are loss of riparian vegetation, habitat

Table 1 Strategies adopted for restoration of riparian regions around the world

Sl. No	Site and country	Strategy	Reference
1	Salt River & other Rivers, Western USA	Process oriented approach—the restoration is based on the physical process (mainly flow regulation) and selection of plants which present in the undisturbed regions and type of vegetation at specific sites	White and Stromberg (2011); Goodwin et al. (1997); Stromberg (2001)
2	River Ebro, Spain	Restoring connectivity between rivers and floodplains—all embankments were removed, instead of planting, facilitated for natural seed deposition and germination during flooding, ie. Natural re-establishment of riparian vegetation	Gumiero et al. 2013
3	Steamers of New Zealand	Riparian management—livestock exclusion, creating riparian buffer,	McKergow et al. (2016)
4	Northeast Oregon, USA	Ecological approaches—Passive restoration	Kauffman et al. (1995)
5	Truckee River, Nevada, USA	Flow regulation and planting of phreatophytic plants	Rood et al. 2003
6			
7	North America	Careful clump transplanting of cane (<i>arundinaria gigantea</i>) and maintenance combined with favourable post establishment conditions gave high growth rate	Dattilo and Rhoades (2005)
8	Bridge River, Canada	Controlled flow of water from dams: The delivery of downscaled flow regimes as a strategy to enable the survival, growth and reproduction of aquatic and riparian organisms	Hall et al. (2011)
9	Dolores River Western USA	Participatory approach	Hawkins et al. (1997)
10	lowland streams in Canterbury, New Zealand	Planting of trees	Collins et al. 2013
11	San Luis Rey River, USA	2 stage restoration, 1) selecting proper places which need restoration 2)selecting areas which has to be protected from further interference	Olson and Harris (1997)
12	Riparian areas of Chesapeake Bay watershed in Maryland, USA	Riparian buffer restoration is a more ecologically favorable method than designed channel restoration for bank stabilization	Laub et al. (2013)
13	Denmark (Baltic island Bornholm)	Adjustive ecological restoration: successful restoration with the adjustment between stakeholders and project managers and among the stakeholders	Gamborg et al. (2019)
14	Delaware River, Chesapeake Bay, USA	Physiographic regions such as early to mid successional stands require only natural succession for restoration along with protection	Rheinhardt et al. (2009)
15	Streams of southeastern Iberian Peninsula, Spain	simple planting technique accompanied by monitoring	Salinas and Guirado (2000)
16	Chester River, USA	Avoided the dominance of certain species to grow	Sweeney et al. (2002)

Fig. 3 Proposed steps and processes for riparian ecosystem restoration

destruction, reduced density of aquatic biota, and effect on the livelihood of the stakeholders (Saritha et al. 2019; Iwata et al. 2003). The mapping of these impacts has to be done for understanding the current situation. This phase will assess the stream hydrology and morphology, baseline environmental quality, biodiversity, etc. (Hale et al. 2018). These assessments will help in identifying the potential region for restoration (Kentula 1997). For stream hydrology, the likelihood of flooding, the timing of the peak water table, its rate of decline and inconsistency associated with snowmelt and the overall growing season are very important for successful restoration of indigenous plants and sustainability (Thibault et al. 2017).

Prioritising the site for riparian restoration is crucial and it is necessary to understand the geomorphic conditions, plant species composition, and community structure for the development of better strategies (Kentula 1997). The land use–land cover and wetness data can be used for identifying a potential site for restoration as confirmed by Russell et al. (1997) by using a GIS platform for prioritising areas based on patch size and proximity to the riparian system. Hawkins et al. (1994) suggested that sites near the existing undisturbed riparian vegetation and away from urban development will have the maximum potential for effective long-term restoration. The presence or absence of invaders, endurers (resprouting species), and resistors have to be assessed to plan the restoration activity (Naiman and Decamps 1991). The presence of endurers will include the possibility of applying both passive and active restoration. The plant diversity

assessment can be used to identify various plant species for restoration (Meli et al. 2013). The selected one shall be the most suitable native species that would not change the forest profile (Nilsson et al. 2010). The selection will also consider the stream morphology and suitable sites (Olson et al., 2007; Marshall et al. 2013; Hortobágyi et al. 2018). The fine-rooted plants will be kept at the edges, where there are higher chances of erosion. Large trees will be planted towards the interior (Goodwin et al. 1997; Stromberg 2001; White and Stromberg 2011). The planting of rooted plants along the edges of the river banks/ sediment bar, along with debris trapping, is required for river bank stabilisation (Rood et al. 2003; McKergow et al. 2016).

The planning of restoration activities should be done in the first phase. It consists of time and area for planting, development of nursery for the indigenous plants, identification of parameters to be monitored, finding out nature-based solutions, etc. (Mohan et al. 2020). The second phase of restoration activities consists of creating awareness and stakeholder involvement, nursery development, bank stabilisation, and planting (Gamborg et al. 2019). If the restoration activities are in a participatory manner, the discussion on the preliminary assessment and the strategies for restoration with stakeholders are very significant (Hawkins, 1994). Their help is needed for collecting and nurturing saplings and planting. It will also help to understand the indigenous knowledge of elder stakeholders on riparian forests and past natural disasters of the region. The ability to work with stakeholders, the willingness to adjust along high levels of

trust and leveling of expectations at the very beginning are key to the success of the restoration process (Hawkins, 1994; Mohan et al. 2020). Such an approach is known as ‘adjustive ecological restoration’, where incorporating the stakeholders into the restoration activity enhances the mutual benefits and understanding (Gamborg et al. 2019). The participatory riparian forest management method is where the local community prepares nurseries and carries out planting. The planting ensures their financial security as well as employment opportunities from the site preparation and monitoring of the restoration programme (Gamborg et al. 2019). Local indigenous communities can help in identifying endangered plants by utilising their centuries-old knowledge of the land and forests, supporting the success of the restoration project (Hawkins, 1994). They can also help in identifying the required flora for planting.

At the community level, sub-groups should prepare a list of lost plants, nursery care, planting, and subsequent care at various levels (Nishat and Biswas 2005; Haase and Davis 2017). Suitable plants should be found in natural landscapes and cultural landscapes (Schmidt et al. 2019). For cultural landscapes, plants should be selected and planted in the riparian area close to farmlands for coastal protection and erosion prevention. Non-timber forest resources should be given more prominence in local indigenous landscapes (He et al. 2009). The indigenous communities of the South-West United States serve as a world-class model of riparian eco-restoration with the cooperation of such local communities, along with the riverine forests of the Colorado River and its tributaries (Miller et al. 1996; Phillips, 1998; Voggeser 2006). Riparian restoration can be conducted passively or actively (Fig. 3). The trees for active or passive restoration can be selected by understanding the tree species dominance, which can be measured by various methods. For example, Meli et al. (2013) used the importance value index, where abundance and—size correlations were used to select tree species suitable for passive or active restoration. The development of the understory is highly significant in restoring riparian ecosystems. As per McClain et al. (2011), only common, native, understory plants can be restored by passive approaches that are site-specific, along with an active relay floristic model to restore the entire understory species. The post-monitoring and maintenance phases include the planning of periodic monitoring of specific parameters for assessing the success of the restoration (Mohan et al. 2020). Replanting perished saplings with new ones and controlling local livestock and wildlife grazing are included in this phase (Collins et al. 2013; McKergow et al. 2016).

3.2 Geoinformatics as a Tool in RER

The advancements in geoinformatics systems and application tools integrated with various satellite data products have

a wide range of applications in biodiversity conservation and preservation of ecosystems, including riparian ecosystems and their services (Joseph et al. 2011; Bhunia, and Shit 2022). In all phases of ecosystem restoration, geoinformatics plays a vital role (Bethel et al. 2011). In the pre-assessment phase, a bird’s eye view of the riparian ecosystem, its associated watershed and catchment vegetation through temporal analysis will provide information on the health of the river, its rate of degradation, and fragmentation of the riparian corridor (Fremier et al. 2015; Ahn and Kin, 2017; Piégay et al. 2020). The breaks in the canopy of the riparian corridor will lead to species isolation, especially of arboreal wildlife. Integrating topo-hydrological factors and riverine morphometric data into the NDVI and temporal changes in the vegetation is effective in prioritising the potential zones for watershed management and restoration activities (Sinha et al. 2008; Aher et al. 2014; Ahmed et al. 2017; Arabameri et al. 2018; Rahmati et al. 2019; Huylenbroeck et al. 2020). In the restoration phase, hydrological modeling provides information on the intensity of discharge, possible flood areas, and sedimentation. During floods, this information also supports the local administration for preparedness, monitoring, mitigation, and flood risk assessment (Dang and Kumar, 2017). During the final stage of eco-restoration, the monitoring phase, geoinformatics supports assessing the improvement of the niche of various life forms (Lengyel et al. 2020; Hortobágyi et al. 2018) and the health regaining rate of various ecosystems along the riparian corridor (Golet et al. 2008; Hausner et al. 2018).

3.3 Factors Affecting Restoration

The success of the restoration of the riparian ecosystem is influenced by various factors. The biotic, abiotic, social and governance aspects are major conditions affecting riparian restoration (Fig. 4) (Arsenio et al. 2020; Mohan et al. 2020). Biotic factors include the selection of species, influence of invasive species, the role of endurers, resistors, and hydrochory, and passive or active restoration (Naiman and Decamps, 1991; Nilsson et al. 2010). The passive strategy may take more time than the active strategy in terms of restoration activity. If there are no endurers or no chance of hydrochory, active restoration is recommended (Nilsson et al. 2010). The complete degradation of riparian landscapes is very difficult to inverse; however, if resistors are present, the restoration of the system can be faster. Browsing is an important factor as most riparian regions are exposed to either local wildlife or domestic livestock (Opperman and Merenlender, 2000). Confining browsing during the restoration time is important to enhance the growth of plants (Marshall et al. 2013). The type of restoration (ie., passive or active) will define the rate of restoration (Holl and Aide 2011). Not only is the rate of passive restoration lower than

Fig. 4 Factors affecting restoration of riparian ecosystems

active restoration it also involves a chance of invasion of species. However, during active restoration, the anthropogenic input is higher during the planting and growth phases. In addition, the control of browsing is remarkably high, despite some checking of the restoration process in some regions with more wildlife, viz., reserved forest areas (Opperman and Merenlender, 2000). The restoration of a specific degraded area should be started shortly to prevent the colonisation of invasive species, which is very difficult to remove once they reach maximum growth. Active restoration can sometimes be a failure resulting in little change or further degradation (Kauffman et al. 1995).

The abiotic factors influencing the riparian restoration are mainly stream-geomorphology, hydrological regime, degree of degradation, human interferences, such as encroachment and sand mining (Wissmar and Beschta, 1998; Marshall et al. 2013), etc. The intensity and frequency of floods may significantly influence the regeneration of forests. Human interventions such as damming and mining can change stream hydrology, geomorphology and sediment availability. Sedimentation during a seasonal flood is inevitable for the growth of riparian plants (Richter and Richter 2000; Rood et al. 2003). Soil drainage and fertility are also limiting factors for the successful growth of certain woody grass species usually used in restoration. For example, these parameters should be assessed before adding organic amendments for woody grass species like *A. gigantea* (Dattilo and Rhoades 2005). According to Stromberg (2001), among the various abiotic factors, the reinstating of water flow, along with

sufficient sediment supply, are the key elements for successful riparian ecosystem restoration. Hydrology has a significant influence on riparian restoration, depending on the type of ecosystem (Richter and Richter 2000). If it is a dry landscape, it purely depends on the groundwater, whereas in other regions it depends on the surface water flow (Thibault et al. 2017). The changes in groundwater levels may take years to become evident, hence it will be very important to understand the alterations before the restoration to provide insights into the adaptability of the ecosystem (Eamus and Froend 2006).

The increase in streamflow even in low intensity can enhance the restoration process as evident from the restoration studies in the Colorado River (Schlatter et al. 2017). It is more effective in arid regions (Glenn et al. 2017). Hickey et al. (2020) established a flow ecology model for riparian restoration, where they regulated water flows from reservoirs to support the restoration. The ecological variables in the model included timing of seed dispersal, tolerable rates of flow recession, and tolerable duration of inundation, following germination and early seedling establishment. Hydrological variables in the model included peak flow timing, rate of flow recession following the peak, and duration of inundation. Among the social factors, the awareness and participation of stakeholders are important in the success of riparian restoration (Arsenio et al. 2020). Their involvement is required during the restoration as well as post-monitoring period. Proper management of agricultural lands surrounding the riparian ecosystem is required to control the nutrient

and pollutants inflow. Domestic livestock grazing is linked with livelihoods, which can affect restoration activities.

The success of any eco-restoration programme depends on proper governance (Fig. 4) and policies. This enhances the research, planning, and funding for such programmes (Holmes et al. 2004; Shafroth et al. 2008; McKergow et al. 2016). The lack of policies and cooperation, both at the national and international levels, remains a negative influence on riparian restoration. New Zealand's state policy for a restoration programme they started in 1992 is to carry out riparian restoration for filtering agricultural spill over and ensuring good water quality and habitat (McKergow et al. 2016; Daigneault et al. 2017). Daigneault et al. (2017) found that this national-level restoration programme provided positive benefits to the country.

3.4 Assessment of Riparian Restoration

The sharing of information on the ecology of riparian ecosystems, reasons for degradation, and strengths and limitations of various restoration approaches are essential for improving the success rate of such restoration projects (Goodwin et al. 1997; Stromberg 2001). The important questions to be asked for the success of restoration programmes are:

- What factors caused the loss of the riparian forest?
- What factors have allowed for the establishment of exotics?

Stromberg (2001) opined that the integral part of riparian restoration should be adaptive research and management policies, as situations for each restoration programme are different. The impact of riparian restoration is assessed by comparing control sites. Before-after control-impact (BACI) design by Muller et al. (2016) is an example of comparative evaluation. The evaluation of the impact of restoration can be based on three factors—biotic, abiotic, and social (Fig. 5). Biotic factors include the increase in plant growth, floral diversity and faunal diversity. The biodiversity assessment will indicate the changes that occurred in floral and faunal components after the restoration (Carline and Walsh 2007). It is indicated that the evaluation of a better-known taxonomic group may be inadequate to represent the response of biodiversity in the restored area. Apart from biodiversity, the abundance of understory plants, increase in native plants and herbaceous flora, decrease in exotic or weed plants in the restored area, etc., are all considered for the assessment (McClain et al., 2011; Lennox et al. 2011; Hough-Snee et al. 2013). According to Salinas et al. (2000), simple planting and monitoring of plants after seven years indicated the

Fig. 5 Evaluation parameters for the success of a riparian ecosystem restoration

success of the restoration. However, they indicated that more time is required to achieve coverage, frequency, and species composition than that for undisturbed zones. The survival of seedlings can also be counted as part of the biotic factor during the assessment (Sweeney et al. 2002). Satellite and precipitation data are used for understanding the effect of restored ecosystems. The NDVI index is used and compared with pre and post-restoration (Hausner et al. 2018). The faunal diversity includes macro-invertebrates, birds, reptiles, soil macrofauna, fishes, etc. (Rood et al. 2003; Golet et al. 2011). The faunal diversity can indicate the success of riparian ecosystem restoration (Golet et al. 2008 and 2011; Gollan et al. 2011; Wortley et al. 2013; Mitchell et al. 2021); however, a few studies have shown that not all species can be taken into account. For example, using prey availability was not successful in the evaluation of the restoration programme at lower Colorado River (Rubin et al. 2019).

The abiotic factors can be generally categorised into stream-related and others (Fig. 5). Stream-related measurements include analysis of channel morphology, suspended sediment content, and sedimentation process (Lennox et al. 2011). De Mello et al. (2017) used watershed simulation modeling to simulate streamflow, suspended sediments and nutrients. An increase in groundwater level can also indicate the positive impact of riparian restoration (Halik et al. 2019). Other parameters indicating the impact of riparian restoration are shown in Fig. 5. The changes in structural vegetation, especially stem density and crown development, can indicate the impacts of restoration (Hale et al. 2018; Hausner et al. 2018). Hale et al. (2018) depicted the role of increased organic matter loading in terms of litter in the restoration. The assessment of carbon and nutrient stocks and turnover is the most important and feasible parameters to be monitored to understand the recovery of ecosystem functioning in the restored forests (Matzek et al. 2016). The quantity of carbon sequestered in the soils and woody biomass can be assessed for a better understanding of the changes of restoration (Matzek et al. 2018 and 2020). The improvement in water and soil quality parameters is also considered for the evaluation (Meals, 2001; de Mello et al. 2017; Hale et al. 2018). Collins et al. (2013) found an increase in dissolved oxygen and a decrease in turbidity during the restoration at lowland streams in Canterbury, New Zealand. Temporal variability in climate such as an increase in precipitation, temperature variations shall be considered for understanding the success of riparian restoration (Meyer et al. 2010). Lennox et al. (2011) confirmed the availability of habitat to be a significant indicator of ecosystem service by the restored riparian ecosystem, as seen from the potentially improved anadromous fish habitats at the restored site.

The socio-economic parameters mainly include fishery resources, availability of more NTFPs, medicinal plants, and water (Fig. 5). Fishery resources can be increased after the

restoration process as it provides shade and space for spawning ground (Justice et al. 2017). Opperman and Merenlender (2004) found that riparian restoration can produce instream salmonid habitat benefits that are more comprehensive, sustainable, and cost-effective than the benefits generated by instream structures. Instream characteristics significantly affect fish assemblages in a river, hence the improvement in fish assemblages can be used as a measure of restoration success (Paller et al. 2000), indicating the creation of more livelihood options for the local population. The utilisation of medicinal as well as piscicidal plants in the restoration process also help the livelihoods of the local population (Sasi and Mohan, 2018). Daigneault et al. (2017) used economic modeling to understand the benefits of riparian restoration and its relevant costs.

3.5 Benefits of Riparian Restoration

The benefits of riparian restoration can be classified into short-term and long-term benefits. Short-term benefits include water quality improvement (Fig. 6); while long-term benefits include structure restoration and habitat function that may take decades (Parkyn et al. 2003). Short-term biological benefits include the improvement in fish diversity, soil micro, macrofauna, plant biodiversity, etc. (Opperman and Merenlender 2004; Jiménez-Carmona et al., 2020). The positive impact of restoration on the soil/geomorphology are improved riparian bank, soil structure, soil nutrients, etc. (Hale et al. 2018; Matzek et al. 2020). The long-term benefits include increased habitat diversity, development as a wildlife corridor and a refuge for protected species, flood benefit, and improvement in climate change adaptability (Holmes et al. 2004; Gumiero et al. 2013; Matzek et al. 2016). A successful restoration begins from the headwater all the way downstream. The activities in the other regions of the watershed/catchment may affect some of these benefits if restoration is carried out in a specific downstream area. Parkyn et al. (2003) opined that, for clear water, the upper catchment and lower order streams should be unimpacted. The economic analysis of riparian restoration programmes indicates that restored riparian strips are beneficial to climate and freshwater when compared to the implementation costs, even though they do not monetise the increase in biodiversity or stream ecosystem health (Daigneault et al. 2017).

3.6 Limitations

The implementation of laws and policies may not improve the restoration benefits. For example, laws in Brazil have not enhanced the restoration due to the limited awareness of environmental compliance requirements, inadequate technical capacity in mapping the distribution and extent of riparian forests (Nunes et al. 2015). Matzek et al. (2016)

Fig. 6 Long-term and short-term benefits observed in the past riparian ecosystem restoration with respect to time

observed that re-forested sites are still functionally different from the undisturbed areas, despite similarities in vegetation structure, even after the two decades of restoration. It indicates restoration may recreate the vegetation structure, however, it may not reinstate the ecosystem process on the same time scale and may require more time. The success of riparian restoration depends on the communication between stakeholders, management agency and policymakers and they should understand the importance of restoration and the ecological, economical and social means of restoration (Reich et al. 2011). The management and policymakers should be able to identify and communicate the targets and share the responsibilities for restoration among all stakeholders.

The restoration of degraded riparian ecosystems is gaining interest, which will enhance several functions. Still, there are problems with the understanding of channel changes due to restoration changes—whether they will offset the effect of wider catchment pressure, and quantitative measurement of these effects, and so on (Clews et al. 2010). According to Williams et al. (2011), the major constraints for improving restoration activity are:

- a lack of ecological evidence on the effects of restoration efforts
- spending minimum time for restoration efforts
- short-term funding for monitoring
- lack of long-term monitoring for ecosystem recovery

Most of the riparian restoration programmes have short-term objectives and are not monitored systematically. This limits the opportunities to learn from past efforts to restore these ecosystems and improve future restoration activities (Lennox et al. 2011). Williams et al. (2011) opined that an integrated approach including long-term ecological research, within an adaptive hierarchical management framework in policy, is necessary for improving the restoration activity.

4 Distribution of Riparian Restoration Studies Around the Globe

A total of 118 publications on riparian restoration were found based on the keyword restoration of riparian ecosystem in international journals (Fig. 7). The maximum number of studies were observed in the USA, whereas other countries showed an insignificant number of restoration activities (Fig. 7). According to the distribution map, many countries are far behind in riparian restoration, and many are yet to begin. The decadal variation in the number of publications indicated an increase in restoration programmes (Fig. 8), however, a significant impact should be seen in the coming two decades. More countries have to take up the challenge of restoring riparian ecosystems.

Fig. 7 Worldwide distribution of studies published on riparian restoration

Fig. 8 No of publications on riparian restoration during the last four decades around the globe

5 Opportunities for Riparian Restoration

The restoration of ecosystems is one of the SDGs (Yao et al. 2021). The research revealed a complex relationship

between RER and global environmental and biological factors (Fig. 9). RER is directly linked to the achievement of many UN-SDGs, including (i) climate action, (ii) life below water, and (iii) life on land. It is indirectly related to (i) no poverty, (ii) zero hunger, (iii) good health and wellbeing, (iv) gender equality, (v) clean water and sanitation, (vi) sustainable cities and communities, (vii) responsible consumption and production, and (viii) partnerships for the goals (Basak et al. 2021). Mohan et al. (2020) proposed a scheme for sustainable RER, where various stages of restoration activities are centred on the stakeholders, such as local forest-dependent communities and other local stakeholders. This type of RER can utilise rich indigenous knowledge and support the livelihoods of stakeholders (Hawkins, 1994; Gamborg et al. 2019). Such a participatory approach can help to reduce poverty as well as hunger, enhance gender equality, sustainable communities, global partnerships, etc., and are indirectly related to SDG numbers 1, 2, 3, 5, 11 and 17. The participatory approach is highly significant in the scenario of the UN-DESR (2021 to 2030) (Galbraith et al. 2021).

Fig. 9 The global changes by RER and UN SDGs directly and indirectly related to RER

It aims to massively scale up the restoration of degraded and destroyed ecosystems as a proven measure to fight the climate crisis and enhance food security, water supply and biodiversity (Herrick et al. 2019). This will encourage the mobilisation of resources, capacity building, scientific research, etc., and mainstreaming of ecosystem restoration into policies and plans (Molenaar and Cleen 2017). The global, regional and local-level restoration guidelines and plans require a holistic approach focussed on the efforts for restoration as well as on the actions for preventing further degradation. Participatory planning, implementing and monitoring of restoration activities will enhance the resilience of both ecosystems and livelihoods of local communities (Pandit et al. 2018; Abhilash, 2021). In this regard, the present paper is highly significant for discussing riparian ecosystems restoration methods, and the challenges faced by stakeholders to develop policies on mainstreaming riparian ecosystem restorations.

6 Conclusion

The review found that RER programmes are not globally distributed and past programmes were observed to have short-term or long-term benefits with regional and global impacts. The approaches used for the restoration of riparian ecosystems were assessed and developed to offer a consolidated approach for RER. We also reviewed the various parameters used for understanding the success of RER and developed a set of parameters for evaluating the success of future programmes. RER is well linked with the 10 principles of UN-DER. RER will have a significant effect on reducing global warming through carbon sequestration, increasing biodiversity and wildlife movement, while marking an improvement in hydrology, etc. Riparian ecosystems are one of the best options among the various ecosystem restoration projects due to their

unique position in the landscape and their quantum of benefits. RER is directly or indirectly related to most of the UN SDGs. Hence, it is high time to execute RER programmes around the world with international cooperation and involvement. The short-term approach and limited funds, along with improper planning and policy, are the major limitations for riparian restoration. The processes and approaches proposed for riparian restoration can be implemented worldwide, despite slight variations across sites. Governments have to provide more opportunities for research on approaches and evaluation of RER as a part of the UN-DER. It will enhance the restoration of riparian areas with significant ecosystem functions.

Acknowledgements I am thankful to UNDP for supporting a riparian restoration programme in the Chalakkudy river basin, which is one of its first kind in India. I also acknowledge the Department of Environment and Climate Change (DoECC), State Government of Kerala, for the collaboration extended to us for developing an indigenous Miyawaki model forest in Kerala.

Declarations

Conflict of interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

- Abhilash PC (2021) Restoring the unrestored: strategies for restoring global land during the UN decade on ecosystem restoration (UN-DER). *Land* 10:201. <https://doi.org/10.3390/land10020201>
- Aher PD, Adinarayana J, Gorantiwar SD (2014) Quantification of morphometric characterization and prioritization for management planning in semi-arid tropics of India: a remote sensing and GIS approach. *J Hydro* 511:850–860. <https://doi.org/10.1016/j.jhydrol.2014.02.028>
- Ahmed I, Pan ND, Debnath J, Bhowmik M (2017) An assessment to prioritise the critical erosion-prone sub-watersheds for soil conservation in the Gumti basin of Tripura, North-East India. *Environ Monit Assess* 189:1–15. <https://doi.org/10.1007/s10661-017-6315-6>
- Ahn SR, Kim SJ (2017) Assessment of integrated watershed health based on the natural environment, hydrology, water quality, and aquatic ecology. *Hydrol Earth Syst Sci* 21:5583–5602. <https://doi.org/10.5194/hess-21-5583-2017>
- Álvarez-Yépiz JC (2020) Restoration ecology in the Anthropocene: learning from responses of tropical forests to extreme disturbance events. *Restor Ecol* 28:271–276. <https://doi.org/10.1111/rec.13117>
- Arabameri A, Pradhan B, Pourghasemi HR, Rezaei K (2018) Identification of erosion-prone areas using different multi-criteria decision-making techniques and GIS Geomatics. *Geomatics Nat Hazards Risk* 9:1129–1155. <https://doi.org/10.1080/19475705.2018.1513084>
- Arsenio P, Rodríguez-González PM, Bernez IS, Dias F, Bugalho MN, Dufour S (2020) Riparian vegetation restoration: Does social perception reflect ecological value? *River Res Appl* 36: 907–920. <https://doi.org/10.1002/rra.3514>
- Basak SM, Hossain MS, Tusznió J, Grodzińska-Jurczak M (2021) Social benefits of river restoration from ecosystem services perspective: a systematic review. *Environ Sc Policy* 124:90–100. <https://doi.org/10.1016/j.envsci.2021.06.005>
- Bendix J (1999) Stream power influence on southern Californian riparian vegetation. *J Veg Sci* 10:243–252. <https://doi.org/10.2307/3237145>
- Bendix J, Hupp CR (2000) Hydrological and geomorphological impacts on riparian plant communities. *Hydrol Process* 14:2977–2990. [https://doi.org/10.1002/1099-1085\(200011/12\)14:16/17%3C2977](https://doi.org/10.1002/1099-1085(200011/12)14:16/17%3C2977)
- Bethel MB, Brien LF, Danielson EJ, Laska SB, Troutman JP, Boshart WM, Phillips MA (2011) Blending geospatial technology and traditional ecological knowledge to enhance restoration decision-support processes in coastal Louisiana. *J Coast Res* 27(3):555–571. <https://doi.org/10.2112/JCOASTRES-D-10-00138.1>
- Bhunia GS, Shit PK (2022) River corridor mapping and monitoring using geospatial technology. In: *River Health and Ecology in South Asia* (pp 329–339). Springer, Cham. https://doi.org/10.1007/978-3-030-83553-8_14
- Bigley RE, Deisenhofer FU (2006) Implementation procedures for the habitat conservation plan riparian forest restoration strategy. Washington State Department of Natural Resources, Scientific Support Section, Olympia, Washington.
- Bolla Pittaluga M, Repetto R, Tubino M (2003) Channel bifurcation in braided rivers: Equilibrium configurations and stability. *Water Resour Res* 39. <https://doi.org/10.1029/2001WR001112>
- Capon SJ, Chambers LE, Mac Nally R, Naiman RJ, Davies P, Marshall N, Pittock J, Reid M, Capon T, Douglas M, Catford J (2013) Riparian ecosystems in the 21st century: hotspots for climate change adaptation? *Ecosystems* 16, 359–381. <https://doi.org/10.1007/s10021-013-9656-1>
- Capon SJ, Pettit NE (2018) Turquoise is the new green: restoring and enhancing riparian function in the Anthropocene. *Ecol Manage Restor* 19:44–53. <https://doi.org/10.1111/emr.12326>
- Carline RF, Walsh MC (2007) Responses to riparian restoration in the spring creek watershed, central Pennsylvania. *Restor Ecol* 15:731–742. <https://doi.org/10.1111/j.1526-100X.2007.00285.x>
- CBD (2019). ‘Decision XIII/5. Ecosystem restoration: short-term action plan’. Retrieved from <https://www.cbd.int/doc/decisions/cop-13/cop-13-dec-05-en.pdf>
- Celentano D, Rousseau GX, Engel VL, Façanha CL, de Oliveira EM, de Moura EG (2014) Perceptions of environmental change and use of traditional knowledge to plan riparian forest restoration with relocated communities in Alcântara. *Eastern Amazon J Ethnobiol Ethnomedicine* 10:1–14. <https://doi.org/10.1186/1746-4269-10-11>
- Chazdon RL, Falk DA., Banin LF, Wagner M, J Wilson S., Grabowski, RC, Suding KN (2021) The intervention continuum in restoration ecology: rethinking the active–passive dichotomy. *Restor Ecol* e13535. <https://doi.org/10.1111/rec.13535>
- Chen CHEN, Ejack L, Chenier MR, Whalen JK (2021) Earthworm functional groups are related to denitrifier activity in riparian soils. *Pedosphere* 31:413–422. [https://doi.org/10.1016/S1002-0160\(20\)60084-4](https://doi.org/10.1016/S1002-0160(20)60084-4)
- Clews E, Vaughan IP, Ormerod SJ (2010) Evaluating the effects of riparian restoration on a temperate river-system using standardized habitat survey. *Aquat Conserv Mar Freshwater Ecosyst* 20:96–104. <https://doi.org/10.1002/aqc.1096>
- Collins KE, Doscher C, Rennie HG, Ross JG (2013) The effectiveness of riparian ‘restoration’ on water quality—a case study of low-land streams in Canterbury, New Zealand. *Restor Ecol* 21:40–48. <https://doi.org/10.1111/j.1526-100X.2011.00859.x>
- Cornejo-Denman L, Romo-Leon JR, Castellanos AE, Diaz-Caravantes RE, Moreno-Vázquez JL, Mendez-Estrella R (2018) Assessing riparian vegetation condition and function in disturbed sites of

- the arid northwestern Mexico. *Land* 7:13. <https://doi.org/10.3390/land7010013>
- Coulthard TJ (2005) Effects of vegetation on braided stream pattern and dynamics. *Water Resour. Res.*, 41. <https://doi.org/10.1029/2004WR003201>
- Cowger W, Gray AB, Schultz RC (2019) Anthropogenic litter cleanups in Iowa riparian areas reveal the importance of near-stream and watershed scale land use. *Environ Pollut* 250:981–989
- Curtis PG, Slay CM, Harris NL, Tyukavina A, Hansen MC (2018) Classifying drivers of global forest loss. *Science* 361:1108–1111. <https://doi.org/10.1126/science.aau3445>
- Daigneault AJ, Eppink FV, Lee WG (2017) A national riparian restoration programme in New Zealand: Is it value for money? *J Environ Manage* 187:166–177. <https://doi.org/10.1016/j.jenvman.2016.11.013>
- Dang ATN, Kumar L (2017) Application of remote sensing and GIS-based hydrological modelling for flood risk analysis: a case study of District 8, Ho Chi Minh city. *Vietnam Geomatics Nat Hazards Risk Geomatics* 8:1792–1811. <https://doi.org/10.1080/19475705.2017.1388853>
- Dattilo AJ, Rhoades CC (2005) Establishment of the woody grass *Arundinaria gigantea* for riparian restoration. *Restor Ecol* 13(4):616–622. <https://doi.org/10.1111/j.1526-100X.2005.00079.x>
- Dave R, Saint-Laurent C, Murray L, Antunes Daldegan G, Brouwer R, de Mattos Scaramuzza CA, and Pearson T (2018) Second Bonn challenge progress report. Application of the Barometer in, 2019. <https://doi.org/10.2305/IUCN.CH.2019.06.en>
- de Mello K, Randhir TO, Valente RA, Vettorazzi CA (2017) Riparian restoration for protecting water quality in tropical agricultural watersheds. *Ecol Eng* 108:514–524. <https://doi.org/10.1016/j.ecoleng.2017.06.049>
- Dybala KE, Matzek V, Gardali T, Seavy NE (2018) Carbon sequestration in riparian forests: a global synthesis and meta-analysis. *Glob Change Biol* 25(1):57–67
- Eamus D, Froend R (2006) Groundwater-dependent ecosystems: the where, what and why of GDEs. *Aust J Bot* 54:91–96. <https://doi.org/10.1071/BT06029>
- Easa PS (2005) Asian Elephant in India: A review. In: *Right of Passage: Elephant Corridors of India*, Wildlife Trust of India. New Delhi.
- Ewel KC, Cressa C, Kneib RT, Lakes PS, Levin LA, Palmer MA, Snelgrove P, Wall DH (2001) Managing critical transition zones. *Ecosystems* 4:452–460. <https://doi.org/10.1007/s10021-001-0106-0>
- FAO (2020) The report on the State of the World's Forests indicates a positive change in our net forest area. <https://www.fao.org/3/ca8642en/ca8642en.pdf>
- Feng X, Fu B, Lu N, Zeng Y, Wu B (2013) How ecological restoration alters ecosystem services: an analysis of carbon sequestration in China's Loess Plateau. *Sci Rep* 3(1):1–5. <https://doi.org/10.1038/srep02846>
- Flores BM, de Sa Dechoum M, Schmidt IB, Hirota M, Abrahão A, Verona L, Oliveira RS (2021) Tropical riparian forests in danger from large savanna wildfires. *J Appl Ecol* 58(2):419–430. <https://doi.org/10.1111/1365-2664.13794>
- Flores-Díaz AC, Castillo A, Sánchez-Matías M, Maass M (2014) Local values and decisions: views and constraints for riparian management in western Mexico. *Knowl Managt Aquatic Ecosyst* 414:06. <https://doi.org/10.1051/kmae/2014017>
- Fremier AK, Kiparsky M, Gmur S, Aycrigg J, Craig RK, Svancara LK, Goble DD, Cosens B, Davis FW, Scott JM (2015) A riparian conservation network for ecological resilience. *Biol Conserv* 191:29–37. ISSN 0006–3207. <https://doi.org/10.1016/j.biocon.2015.06.029>
- Galbraith M, Towns DR, Bollard B, MacDonald EA (2021) Ecological restoration success from community and agency perspectives: exploring the differences. *Restor Ecol* 29(5):e13405. <https://doi.org/10.1111/rec.13405>
- Gamborg C, Morsing J, Raulund-Rasmussen K (2019) Adjustive ecological restoration through stakeholder involvement: a case of riparian landscape restoration on privately owned land with public access. *Restor Ecol* 27:1073–1083. <https://doi.org/10.1111/rec.12955>
- Gann GD, McDonald T, Walder B, Aronson J, Nelson CR, Jonson J, Dixon KW (2019) International principles and standards for the practice of ecological restoration. *Restor Ecol* 27(S1), S1–S46. <https://doi.org/10.1111/rec.13035>
- Glenn EP, Nagler PL, Shafroth PB, Jarchow CJ (2017) Effectiveness of environmental flows for riparian restoration in arid regions: a tale of four rivers. *Ecol Eng* 106:695–703. <https://doi.org/10.1016/j.ecoleng.2017.01.009>
- Golet GH, Gardali T, Hunt JW, Koenig DA, Williams NM (2011) Temporal and taxonomic variability in response of fauna to riparian restoration. *Restor Ecol* 19(1):126–135. <https://doi.org/10.1111/j.1526-100X.2009.00525.x>
- Golet GH, Gardali T, Howell CA, Hunt J, Luster RA, Rainey W, Roberts MD, Silveira J, Swagerty H, Williams N (2008) Wildlife response to riparian restoration on the Sacramento River. *San Franc Estuary Watershed Sci* 6 <https://escholarship.org/uc/item/4z17h9qm>.
- Gollan JR, Reid CA, Barnes PB, Wilkie L (2011) The ratio of exotic-to-native dung beetles can indicate habitat quality in riparian restoration. *Insect Conserv Divers* 4(2):123
- González E, Sher AA, Tabacchi E, Masip A, Poulin M (2015) Restoration of riparian vegetation: a global review of implementation and evaluation approaches in the international, peer-reviewed literature. *J Environ Manage* 158:85–94. <https://doi.org/10.1016/j.jenvman.2015.04.033>
- Goodwin CN, Hawkins CP, Kershner JL (1997) Riparian restoration in the Western United States: overview and perspective. *Restor Eco* 5:4–14. <https://doi.org/10.1111/j.1526-100X.1997.tb00200.x>
- Gumiero B, Mant J, Hein T, Elso J, Boz B (2013) Linking the restoration of rivers and riparian zones/wetlands in Europe: sharing knowledge through case studies. *Ecol Eng* 56: 36–50. <https://doi.org/10.1016/j.ecoleng.2012.12.103>
- Hall AA, Rood SB, Higgins PS (2011) Resizing a river: a downscaled, seasonal flow regime promotes riparian restoration. *Restor Ecol* 19(3):351–359. <https://doi.org/10.1111/j.1526-100X.2009.00581.x>
- Haase DL, Davis AS (2017) Developing and supporting quality nursery facilities and staff are necessary to meet global forest and landscape restoration needs. *Reforesta*, (4): 69–93. <https://doi.org/10.21750/REFOR.4.06.45>
- Hale R, Reich P, Daniel T, Lake PS, Cavnaro TR (2018) Assessing changes in structural vegetation and soil properties following riparian restoration. *Agric Ecosyst Environ* 252:22–29. <https://doi.org/10.1016/j.agee.2017.09.036>
- Halik Ü, Aishan T, Betz F, Kurban A, Rouzi A (2019) Effectiveness and challenges of ecological engineering for desert riparian forest restoration along China's largest inland river. *Ecol Eng* 127:11–22. <https://doi.org/10.1016/j.ecoleng.2018.11.004>
- Hancock CN, Ladd PG, Froend RH (1996) Biodiversity and management of riparian vegetation in Western Australia. *Forest Ecol Manage* 85(1–3):239–250. [https://doi.org/10.1016/S0378-1127\(96\)03761-9](https://doi.org/10.1016/S0378-1127(96)03761-9)
- Hausner MB, Huntington JL, Nash C, Morton C, McEvoy DJ, Piliod DS, Hegewisch KC, Daudert B, Abatzoglou JT, Grant G (2018) Assessing the effectiveness of riparian restoration projects using Landsat and precipitation data from the cloud-computing application ClimateEngine. *org. Ecol Eng* 120:432–440. <https://doi.org/10.1016/j.ecoleng.2018.06.024>

- Hawkins CP (1994) What are riparian ecosystems and why are we worried about them. *Nat Resour Environ Issues* 1:2. <https://digitalcommons.usu.edu/nrei/vol1/iss1/2/>.
- Hawkins CP, Bartz KL, Neale CM (1997) Vulnerability of riparian vegetation to catastrophic flooding: implications for riparian restoration. *Restor Ecol* 5:75–84. <https://doi.org/10.1111/j.1526-100X.1997.tb00207.x>
- He J, Zhou Z, Weyerhaeuser H, Xu J (2009) Participatory technology development for incorporating non-timber forest products into forest restoration in Yunnan. *Southwest China Forest Ecol and Manage* 257(10):2010–2016. <https://doi.org/10.1016/j.foreco.2009.01.041>
- Herrick JE, Abrahamse T, Abhilash PC, Ali SH, Alvarez-Torres P, Barau AS, Branquinho C, Chhatre A, Chotte JL, Von Maltitz GP (2019) Land restoration for achieving the sustainable development goals: An international resource panel think piece. United Nations Environment Programme. <http://hdl.handle.net/10204/11240>.
- Hickey JT, Shafroth PB, Fields WL (2020) Flow-ecology modeling to inform reservoir releases for riparian restoration and management. *Hydrol Process* 34:4576–4591. <https://doi.org/10.1002/hyp.13901>
- Holl KD, Aide TM (2011) When and where to actively restore ecosystems? *Forest Wetlands Ecol Manage Wetlands* 261:1558–1563. <https://doi.org/10.1016/j.foreco.2010.07.004>
- Holmes TP, Bergstrom JC, Huszar E, Kask SB, Orr F III (2004) Contingent valuation, net marginal benefits, and the scale of riparian ecosystem restoration. *Ecol Econ* 49:19–30. <https://doi.org/10.1016/j.ecolecon.2003.10.015>
- Hortobágyi B, Corenblit D, Steiger J, Peiry JL (2018) Niche construction within riparian corridors. Part I: Exploring biogeomorphic feedback windows of three pioneer riparian species (Allier River, France). *Geomorphology (amst)* 305:94–111. <https://doi.org/10.1016/j.geomorph.2017.08.048>
- Hough-Snee N, Roper BB, Wheaton JM, Budy P, Lokteff RL (2013) Riparian vegetation communities change rapidly following passive restoration at a northern Utah stream. *Ecol Eng* 58:371–377. <https://doi.org/10.1016/j.ecoleng.2013.07.042>
- Huber O, Zent S (1995) Indigenous people and vegetation in the Venezuelan Guayana: some ecological considerations. *Scientia Guianæ* 5:37–64
- Huylensbroeck L, Laslier M, Dufour S, Georges B, Lejeune P, Michez A (2020) Using remote sensing to characterize riparian vegetation: a review of available tools and perspectives for managers. *J Environ Manage* 267:110652. <https://doi.org/10.1016/j.jenvman.2020.110652>
- Iwata T, Nakano S, Inoue M (2003) Impacts of past riparian deforestation on stream communities in a tropical rain forest in Borneo. *Ecol Appl* 13:461–473. [https://doi.org/10.1890/1051-0761\(2003\)013\[0461:IOPRDO\]2.0.CO;2](https://doi.org/10.1890/1051-0761(2003)013[0461:IOPRDO]2.0.CO;2)
- Jiménez-Carmona E, Herrera-Rangel J, Renjifo LM, Armbrrecht I (2020) Restoration of riparian forest corridors: eight years monitoring the diversity of soil ants in an Andean rural landscape. *Insect Conserv Diversity* 13:384–392. <https://doi.org/10.1111/icad.12401>
- Johnsingh AJT, Prasad SN, Goyal SP (1990) Conservation of the ChillaMotichur Corridor for elephant movement in Rajaji-Corbett National Parks area. *India Biol Conserv* 51:125–138. [https://doi.org/10.1016/0006-3207\(90\)90107-Z](https://doi.org/10.1016/0006-3207(90)90107-Z)
- Joseph S, Murthy MSR, Thomas AP (2011) The progress on remote sensing technology in identifying tropical forest degradation: a synthesis of the present knowledge and future perspectives. *Environ Earth Sc* 64(3):731–741. <https://doi.org/10.1007/s12665-010-0893-8>
- Justice C, White SM, McCullough DA, Graves DS, Blanchard MR (2017) Can stream and riparian restoration offset climate change impacts to salmon populations? *J Env Manage* 188:212–227. <https://doi.org/10.1016/j.jenvman.2016.12.005>
- Kauffman JB, Case RL, Lytjen D, Otting N, Cummings DL (1995) Ecological approaches to riparian restoration in northeast Oregon. *Restor Manage Notes* 13, 12–15. <https://www.jstor.org/stable/43440404>.
- Kaylor MJ, Warren DR (2017) Linking riparian shade and the legacies of forest management to fish and vertebrate biomass in forested streams. *Ecosphere* 8:e01845. <https://doi.org/10.1002/ecs2.1845>
- Kennedy LJ, Tiller RL, Stutz JC (2002) Associations between arbuscular mycorrhizal fungi and *Sporobolus wrightii* in riparian habitats in arid South-western North America. *J Arid Environ* 50:459–475. <https://doi.org/10.1006/jare.2001.0899>
- Kentula ME (1997) Riparian restoration. *Restor Ecol* 5(4). <http://pas-cal-francis.inist.fr/vibad/index.php?action=getRecordDetail&andidt=418971>.
- Kimmerer R (2011) Restoration and reciprocity: the contributions of traditional ecological knowledge. Island Press, Washington, DC. https://doi.org/10.5822/978-1-61091-039-2_18
- Klapproth JC, Johnson JE (2009) Understanding the science behind riparian forest buffers: effects on water quality. Virginia Cooperative Extension. <http://hdl.handle.net/10919/48062>.
- Kondolf GM, Larson M (1995) Historical channel analysis and its application to riparian and aquatic habitat restoration. *Aquat Conserv Mar Freshwater Ecosyst* 5:109–126. <https://doi.org/10.1002/aqc.3270050204>
- Laub BG, McDonough OT, Needelman BA, Palmer MA (2013) Comparison of designed channel restoration and riparian buffer restoration effects on riparian soils. *Restor Ecol* 21(6):695–703. <https://doi.org/10.1111/rec.12010>
- Lees AC, Peres CA (2008) Conservation value of remnant riparian forest corridors of varying quality for Amazonian birds and mammals. *Conserv Biol* 22(2):439–449. <https://doi.org/10.1111/j.1523-1739.2007.00870.x>
- Lengyel S, Mester B, Szabolcs M, Szepesváry C, Szabó G, Polyák L, Boros Z, Mizsei E, Málnás K, Mérő TO, Aradi C (2020) Restoration for variability: emergence of the habitat diversity paradigm in terrestrial ecosystem restoration. *Restor Ecol* 28:1087–1099. <https://doi.org/10.1111/rec.13218>
- Lennox MS, Lewis DJ, Jackson RD, Harper J, Larson S, Tate KW (2011) Development of vegetation and aquatic habitat in restored riparian sites of California's north coast rangelands. *Restor Ecol* 19:225–233. <https://doi.org/10.1111/j.1526-100X.2009.00558.x>
- Lewis SL, Wheeler CE, Mitchard ET, Koch A (2019) Regenerate natural forests to store carbon. *Nature* 568:25–28. <https://doi.org/10.1038/d41586-019-01026-8>
- Long J, Teale A, Burnette B (2003) Cultural foundations for ecological restoration on the white mountain apache reservation. *Conserv Ecol* 8. <https://www.jstor.org/stable/26271980>.
- Marshall KN, Hobbs NT, Cooper DJ (2013) Stream hydrology limits recovery of riparian ecosystems after wolf reintroduction. *Proc R Soc B* 280:20122977. <https://doi.org/10.1098/rspb.2012.2977>
- Matzek V, Warren S, Fisher C (2016) Incomplete recovery of ecosystem processes after two decades of riparian forest restoration. *Restor Ecol* 24:637–645. <https://doi.org/10.1111/rec.12361>
- Matzek V, Stella J, Ropion P (2018) Development of a carbon calculator tool for riparian forest restoration. *Appl Veg Sci* 21:584–594. <https://doi.org/10.1111/avsc.12400>
- Matzek V, Lewis D, O'Geen A, Lennox M, Hogan SD, Feirer ST, Eviner V, Tate KW (2020) Increases in soil and woody biomass carbon stocks as a result of rangeland riparian restoration. *Carbon Balance Manage* 15:1–15. <https://doi.org/10.1186/s13021-020-00150-7>
- McClain CD, Holl KD, Wood DM (2011) Successional models as guides for restoration of riparian forest understory. *Restor Ecol* 19:280–289. <https://doi.org/10.1111/j.1526-100X.2009.00616.x>

- McKergow LA, Matheson FE, Quinn JM (2016) Riparian management: a restoration tool for New Zealand streams. *Ecol Manage Restor* 17:218–227. <https://doi.org/10.1111/emr.12232>
- Meals DW (2001) Water quality response to riparian restoration in an agricultural watershed in Vermont, USA. *Water Sci Technol* 43:175–182. <https://doi.org/10.2166/wst.2001.0280>
- Meave J, Kellman M, MacDOUGALL ANDREW, Rosales J (1991) Riparian habitats as tropical forest refugia. *Glob Ecol Biogeogr* 69–76. <https://doi.org/10.2307/2997492>
- Meli P, Martínez-Ramos M, ReyBenayas JM (2013) Selecting species for passive and active riparian restoration in Southern Mexico. *Restor Ecol* 21:163–165. <https://doi.org/10.1111/j.1526-100X.2012.00934.x>
- Menon V, Kumar S, Tiwari SK, Easa PS, Sukumar R (2005) Elephant corridors of southern India: An Analysis. In: *Right of Passage: Elephant Corridors of India*, (Eds.). New Delhi.
- Menuz DR, Kettenring KM (2013) The importance of roads, nutrients, and climate for invasive plant establishment in riparian areas in the northwestern United States. *Biol Invasions* 15:1601–1612. <https://doi.org/10.1007/s10530-012-0395-6>
- Meyer CK, Whiles MR, Baer SG (2010) Plant community recovery following restoration in temporally variable riparian wetlands. *Restor Ecol* 18:52–64. <https://doi.org/10.1111/j.1526-100X.2008.00451.x>
- Miller RK, Enotte JE, Martinez CL (1996) Tribal experiences and lessons learned in riparian ecosystem restoration. *General Technical Report RM 272*:198
- Mitchell SR, DeBano SJ, Rowland MM, Burrows S (2021) Feed the bees and shade the streams: riparian shrubs planted for restoration provide forage for native bees. *Restor Ecol* e13525. <https://doi.org/10.1111/rec.13525>
- Mohan M, Saritha VNK, Rameshan M, Chacko A, Gopikrishna VG (2020) Restoring degraded riparian forest ecosystems of the Western Ghats for ecological sustainability. *Restor Ecol* <https://doi.org/10.1111/rec.13254>
- Molenaar C, Cleen M (2017) Sustainable development goals: realizing transitions by sustainable land restoration, land use and management. http://www.worldsoilday2017.eu/conference_presemtation.html
- Mul M, Pettinotti L, Amonoo NA, Bekoe-Obeng E, Obuobie E (2018) Dependence of riparian communities on ecosystem services in Northern Ghana (Vol. 179). *International Water Management Institute (IWMI)*.
- Muller I, Delisle M, Ollitrault M, Bernez I (2016) Responses of riparian plant communities and water quality after 8 years of passive ecological restoration using a BACI design. *Hydrobiologia* 781:67–79. <https://doi.org/10.1007/s10750-015-2349-3>
- Nagaraja BC, Sunil C, Somashekar RK (2014) Protection of riparian habitats to conserve keystone species with reference to *Terminalia arjuna*—A case study from South India. *Biodiversity-The Dynamic Balance of the Planet*. IntechOpen.
- Naiman RJ, Décamps H (1991) Landscape boundaries in the management and restoration of changing environments: a summary. *Ecotones*, Springer, Boston, MA. https://doi.org/10.1007/978-1-4615-9686-8_8
- Naiman RJ, Décamps H (1997) The ecology of interfaces: riparian zones. *Annu Rev Ecol Syst* 28:621–658. <https://doi.org/10.1146/annurev.ecolsys.28.1.621>
- Naiman RJ, Décamps H, Pollock M (1993) The role of riparian corridors in maintaining regional biodiversity. *Ecol Appl* 3:209–212. <https://doi.org/10.2307/1941822>
- Naiman RJ, Beechie TJ, Benda LE, Berg DR, Bisson PA, MacDonald LH, O'Connor MD, Olson PL, Steel EA (1992) Fundamental elements of ecologically healthy watersheds in the Pacific Northwest coastal ecoregion. In *Watershed management*. Springer, New York, NY. https://doi.org/10.1007/978-1-4612-4382-3_6
- Naiman RJ, Fetherston KL, McKay SJ, Chen J (1998) *River Ecology and Management: Lessons From the Pacific Coastal Ecoregion*. New York: Springer-Verlag.
- National Research Council (2002) *Riparian areas: functions and strategies for management*. The National Academies Press, Washington. <https://doi.org/10.17226/10327>
- Nilsson C, Berggren K (2000) Alterations of riparian ecosystems caused by river regulation: dam operations have caused global-scale ecological changes in riparian ecosystems. How to protect river environments and human needs of rivers remains one of the most important questions of our time. *Bioscience* 50:783–792. [https://doi.org/10.1641/0006-3568\(2000\)050\[0783:AORECB\]2.0.CO;2](https://doi.org/10.1641/0006-3568(2000)050[0783:AORECB]2.0.CO;2)
- Nilsson C, Brown RL, Jansson R, Merritt DM (2010) The role of hydrochory in structuring riparian and wetland vegetation. *Biol Rev* 85:837–858. <https://doi.org/10.1111/j.1469-185X.2010.00129.x>
- Nishat AINUN, Biswas SR (2005) Community-based restoration of degraded tropical hill forests: experiences from Krykhong Para, Chittagong Hill Tracts. *Bangladesh Bull National Inst Ecol* 16:1–11
- Nunes SS, Barlow J, Gardner TA, Siqueira JV, Sales MR, Souza CM (2015) A 22 year assessment of deforestation and restoration in riparian forests in the eastern Brazilian Amazon. *Environ Conserv* 42:193–203. <https://doi.org/10.1017/S0376892914000356>
- Oestreicher JS, Farella N, Paquet S, Davidson R, Lucotte M, Mertens F, Saint-Charles J (2014) Livelihood activities and land-use at a riparian frontier of the Brazilian Amazon: quantitative characterization and qualitative insights into the influence of knowledge, values, and beliefs. *Hum Ecol* 42:521–540. <https://doi.org/10.1007/s10745-014-9667-3>
- Olson DH, Anderson PD, Frissell CA, Welsh HH Jr, Bradford DF (2007) Biodiversity management approaches for stream–riparian areas: perspectives for Pacific Northwest headwater forests, microclimates, and amphibians. *Forest Ecol Manage* 246(1):81–107. <https://doi.org/10.1016/j.foreco.2007.03.053>
- Opperman JJ, Merenlender AM (2000) Deer herbivory as an ecological constraint to restoration of degraded riparian corridors. *Restor Ecol* 8:41–47. <https://doi.org/10.1046/j.1526-100X.2000.80006.x>
- Opperman JJ, Merenlender AM (2004) The effectiveness of riparian restoration for improving instream fish habitat in four hardwood-dominated California streams. *North Am J Fish Manage* 24:822–834. <https://doi.org/10.1577/M03-147.1>
- Paller MH, Reichert MJ, Dean JM, Seigle JC (2000) Use of fish community data to evaluate restoration success of a riparian stream. *Ecol Eng* 15:S171–S187. [https://doi.org/10.1016/S0925-8574\(99\)00082-8](https://doi.org/10.1016/S0925-8574(99)00082-8)
- Pandit R, Scholes R, Montanarella L, Brainich A, Barger N, ten Brink B, Cantele M, Erasmus B, Fisher J, Gardner T, Holland T, Kohler F, Kotiaho J, Von Maltitz G, Nangendo G, Parrotta J, Potts M, Prince S, Sankaran M, Willemen L (2018) Summary for policymakers of the assessment report on land degradation and restoration of the intergovernmental science-policy platform on biodiversity and ecosystem services. *The Intergovernmental Platform on Biodiversity and Ecosystem Services*. https://www.ipbes.net/system/tfd/spm_3bi_ldr_digital.pdf?file=1&type=node&id=28335
- Parkyn SM, Davies-Colley RJ, Halliday NJ, Costley KJ, Croker GF (2003) Planted riparian buffer zones in New Zealand: do they live up to expectations? *Restor Ecol* 11:436–447. <https://doi.org/10.1046/j.1526-100X.2003.rec0260.x>
- Pedrollo CT, Kinupp VF, Shepard G Jr, Heinrich M (2016) Medicinal plants at Rio Jauaperi, Brazilian Amazon: ethnobotanical survey and environmental conservation. *J Ethnopharmacol* 186:111–124. <https://doi.org/10.1016/j.jep.2016.03.055>

- Perry LG, Reynolds LV, Beechie TJ, Collins MJ, Shafroth PB (2015) Incorporating climate change projections into riparian restoration planning and design. *Ecohydrol* 8:863–879. <https://doi.org/10.1002/eco.1645>
- Phillips, F. (1998). The Ahakav Tribal Preserve: Colorado River Indian Tribes Initiate a Major Riparian Restoration Program. *Restor Manage Notes* 16, 140–148. www.jstor.org/stable/43439880
- Piégay H, Arnaud F, Belletti B, Bertrand M, Bizzi S, Carbonneau P, Dufour S, Liébault F, Ruiz-Villanueva V, Slater L (2020) Remotely sensed rivers in the Anthropocene: state of the art and prospects. *Earth Surf Process Landf* 45:157–188. <https://doi.org/10.1002/esp.4787>
- Proctor M, Mahr M (2019) Kootenay connect: riparian wildlife corridors for climate change: a preliminary report. Unpubl. Rpt. for Kootenay Conservation Program, Nelson, BC, p 61
- Rahmati O, Samadi M, Shahabi H, Azareh A, Rafiei-Sardooi E, Alilou H, Melesse AM, Pradhan B, Chapi K, Shirzadi A (2019) SWPT: an automated GIS-based tool for prioritization of sub-watersheds based on morphometric and topo-hydrological factors. *Geosci Front* 10(6):2167–2175. <https://doi.org/10.1016/j.gsf.2019.03.009>
- Rameshan M, Roy A, Ramasamy EV (2014) Identification of potential elephant corridor between anamalai landscape and periyar tiger reserve, southern Western Ghats: a geospatial approach. *Int J Geoinformatics* 10:41–52
- Rheinhardt RD, McKenney-Easterling M, Brinson MM, Masina-Rubbo J, Brooks RP, Whigham DF, Armstrong BK (2009) Canopy composition and forest structure provide restoration targets for low-order riparian ecosystems. *Restor Ecol* 17(1):51–59. <https://doi.org/10.1111/j.1526-100X.2007.00333.x>
- Reich P, Lake PS, Williams L, Hale R (2011) On improving the science and practice of riparian restoration. *Ecol Manage Restor*. <https://doi.org/10.1111/j.1442-8903.2011.00561.x>
- Ribeiro JW, Lima AP, Magnusson WE (2012) The effect of riparian zones on species diversity of frogs in Amazonian forests. *Copeia* 2012(3):375–381. <https://doi.org/10.1643/CE-11-117>
- Richardson DM, Holmes PM, Esler KJ, Galatowitsch SM, Stromberg JC, Kirkman SP, Pyšek P, Hobbs RJ (2007) Riparian vegetation: degradation, alien plant invasions, and restoration prospects. *Divers Distrib* 13:126–139. <https://doi.org/10.1111/j.1366-9516.2006.00314.x>
- Richardson JS, Naiman RJ, Bisson PA (2012) How did fixed-width buffers become standard practice for protecting freshwaters and their riparian areas from forest harvest practices? *Freshwater Sci* 31:232–238. <https://doi.org/10.1899/11-031.1>
- Richter BD, Richter HE (2000) Prescribing flood regimes to sustain riparian ecosystems along meandering rivers. *Conserv Biol* 14:1467–1478. <https://doi.org/10.1046/j.1523-1739.2000.98488.x>
- Riis T, Kelly-Quinn M, Aguiar FC, Manolaki P, Bruno D, Bejarano MD, Clerici N, Fernandes MR, Franco JC, Pettit N, Portela AP, Tammeorg O, Tammeorg P, Rodríguez-González PM, Dufour S (2020) Global overview of ecosystem services provided by riparian vegetation. *Bioscience* 70:501–514. <https://doi.org/10.1093/biosci/biaa041>
- Rood SB, Gourley CR, Ammon EM, Heki LG, Klotz JR, Morrison ML, Mosley D, Scopettone GG, Swanson S, Wagner PL (2003) Flows for floodplain forests: a successful riparian restoration. *Bioscience* 53:647–656. [https://doi.org/10.1641/0006-3568\(2003\)053\[0647:FFFFAS\]2.0.CO;2](https://doi.org/10.1641/0006-3568(2003)053[0647:FFFFAS]2.0.CO;2)
- Rubin Z, Rios-Touma B, Kondolf GM, Power ME, Saffarinia P, Natali J (2019) Using prey availability to evaluate lower Colorado River riparian restoration. *Restor Ecol* 27(1):46–53. <https://doi.org/10.1111/rec.12829>
- Russell GD, Hawkins CP, O'Neill MP (1997) The role of GIS in selecting sites for riparian restoration based on hydrology and land use. *Restor Ecol* 5:56–68. <https://doi.org/10.1111/j.1526-100X.1997.tb00205.x>
- Sasi AS, Mohan M (2018) Piscicidal plants used by Malai Pandaram tribes in Achankovil river basin, Kerala: An ethnobiological approach. *Int J Res* 6(1):726–732. <https://doi.org/10.21474/IJAR01/6276>
- Saritha VK, Gopikrishna VG, Rameshan M, Mohan M (2019) Impact of climate change-induced flood on fragile riparian vegetation of braid bars: a case study from Chalakkudy River, Southwest Coast of India. *Clim Change Environ Sustain* 7:143–150. <https://doi.org/10.5958/2320-642X.2019.00019.X>
- Salinas MJ, Blanca G, Romero AT (2000) Evaluating riparian vegetation in semi-arid Mediterranean watercourses in the south-eastern Iberian Peninsula. *Environ Conserv* 27(1):24–35
- Salinas MJ, Guirado J (2002) Riparian plant restoration in summer-dry riverbeds of southeastern Spain. *Restor Ecol* 10(4): 695–702. <https://doi.org/10.1046/j.1526-100X.2002.01050.x>
- Ferreira Rodrigues Sarquis RDS, Rodrigues Sarquis I, Rodrigues Sarquis I, Fernandes CP, Araújo da Silva G, Borja Lima e Silva R., Carvalho JCT (2019) The use of medicinal plants in the river-side community of the Mazagão River in the Brazilian Amazon, Amapá, Brazil: ethnobotanical and ethnopharmacological studies. Evidence-Based Complementary and Alternative Medicine, 2019. <https://doi.org/10.1155/2019/6087509>
- Schlatter KJ, Grabau MR, Shafroth PB, Zamora-Arroyo F (2017) Integrating active restoration with environmental flows to improve native riparian tree establishment in the Colorado River Delta. *Ecol Eng* 106:661–674. <https://doi.org/10.1016/j.ecoleng.2017.02.015>
- Schmidt IB, De Urzedo DI, Piña-Rodrigues FCM, Vieira DLM, De Rezende GM, Sampaio AB, Junqueira RGP (2019) Community-based native seed production for restoration in Brazil—the role of science and policy. *Plant Biol* 21(3):389–397. <https://doi.org/10.1111/plb.12842>
- Seavy NE, Gardali T, Golet GH, Griggs FT, Howell CA, Kelsey R, Small SL, Viers JH, Weigand JF (2009) Why climate change makes riparian restoration more important than ever: recommendations for practice and research. *Ecol Restor* 27:330–338. <https://doi.org/10.3368/er.27.3.330>
- Sekercioglu CH (2009) Tropical ecology: riparian corridors connect fragmented forest bird populations. *Cur Biol* 19(5):R210–R213. <https://doi.org/10.1016/j.cub.2009.01.006>
- SER (Society for Ecological Restoration, Science and Policy Working Group). (2004). TheSER Primer on Ecological Restoration. <http://www.ser.org/>
- Shafroth PB, Beauchamp VB, Briggs MK, Lair K, Scott ML, Sher AA (2008) Planning riparian restoration in the context of Tamarix control in western North America. *Restor Ecol* 16:97–112. <https://doi.org/10.1111/j.1526-100X.2008.00360.x>
- Sinha R, Bapalu GV, Singh LK, Rath B (2008) Flood risk analysis in the Kosi river basin, north Bihar using multi-parametric approach of analytical hierarchy process (AHP). *J Indian Soc Remote Sens* 36:335–349. <https://doi.org/10.1007/s12524-008-0034-y>
- Stanturf JA, Kleine M, Mansourian S, Parrotta J, Madsen P, Kant P, Bolte A (2019) Implementing forest landscape restoration under the Bonn Challenge: a systematic approach. *Ann for Sci* 76(2):1–21. <https://doi.org/10.1007/s13595-019-0833-z>
- Stevens ML (2020) Eco-cultural restoration of riparian wetlands in California: case study of white root (*Carex barbarae* Dewey; Cyperaceae). *Wetlands* 40:2461–2475. <https://doi.org/10.1007/s13157-020-01323-3>
- Stromberg JC (2001) Restoration of riparian vegetation in the southwestern United States: importance of flow regimes and fluvial

- dynamism. *J Arid Environ* 49:17–34. <https://doi.org/10.1006/jare.2001.0833>
- Sukumar R (2006) A brief review of the status, distribution and biology of wild Asian elephants *Elephas maximus*. *International Zoo Yearbook* 40:1–8. <https://doi.org/10.1111/j.1748-1090.2006.00001.x>
- Sutfin NA, Wohl EE, Dwire KA (2016) Banking carbon: a review of organic carbon storage and physical factors influencing retention in floodplains and riparian ecosystems. *Earth Surf Processes Landforms* 41:38–60. <https://doi.org/10.1002/esp.3857>
- Sweeney BW, Czapka SJ, Yerkes T (2002) Riparian forest restoration: increasing success by reducing plant competition and herbivory. 10:392–400. <https://doi.org/10.1046/j.1526-100X.2002.02036.x>
- Thibault JR, Cleverly JR, Dahm CN (2017) Long-term water table monitoring of Rio Grande riparian ecosystems for restoration potential amid hydroclimatic challenges. *Environ Manage* 60:1101–1115. <https://doi.org/10.1007/s00267-017-0945-x>
- Thomas K, Vinodkumar DK, John JM, Shaji M, Nammer PO (2018) A report on the possible interbreeding between Grizzled Giant Squirrel *Ratufa macroura* and Indian Giant Squirrel *Ratufa indica* from Chinnar Wildlife Sanctuary in the southern Western Ghats, India. *J Threat Taxa*: 10(15). <https://doi.org/10.11609/jot.3995.10.15.13024-13028>
- Tockner K, Ward JV (1999) Biodiversity along riparian corridors. *Large Rivers*, 293–310. DOI: <https://doi.org/10.1127/lr/11/1999/293>
- UNEP (2019). New UN Decade on Ecosystem Restoration offers unparalleled opportunity for job creation, food security and addressing climate change opportunity. <https://www.unenvironment.org/news-and-stories/press-release/new-un-decade-ecosystem-restoration-offers-unparalleled-opportunity>.
- Vasconcellos RL, Segat JC, Bonfim JA, Baretta D, Cardoso EJ (2013) Soil macrofauna as an indicator of soil quality in an undisturbed riparian forest and recovering sites of different ages. *Europ J Soil Biol* 58:105–112. <https://doi.org/10.1016/j.ejsobi.2013.07.001>
- Veeramani A, Balasubramanian M, Sanjayankumar, Mathew J (2018) Status and Distribution of Grizzled Giant Squirrel in Chinnar Wildlife Sanctuary, Kerala, India. *Indian Hotspots*. Springer, Singapore. https://doi.org/10.1007/978-981-10-6605-4_11
- Verdone M, Seidl A (2017) Time, space, place, and the Bonn Challenge global forest restoration target. *Restor Ecol* 25(6):903–911. <https://doi.org/10.1111/rec.12512>
- Verry ES, Dolloff CA, Manning ME (2004) Riparian ecotone: a functional definition and delineation for resource assessment. *Water Air Soil Pollut* 4:67–94. <https://doi.org/10.1023/B:WAFO.0000012825.77300.08>
- Voggeser, G. (2006). The Cocopah Tribe, The Colorado River, and Conservation: How Collaboration is Restoring a Cultural and Riparian Ecosystem. *Arizona Riparian Council* 19. <https://static.sustainability.asu.edu/docs/arc/newsletters/Vol19No32006.pdf>.
- Vollmer D, Prescott MF, Padawangi R, Girot C, Grêt-Regamey A (2015) Understanding the value of urban riparian corridors: considerations in planning for cultural services along an Indonesian river. *Landscape Urban Plann* 138:144–154. <https://doi.org/10.1016/j.landurbplan.2015.02.011>
- White JM, Stromberg JC (2011) Resilience, restoration, and riparian ecosystems: case study of a dryland, urban river. *Restor Ecol* 19(1):101–111. <https://doi.org/10.1111/j.1526-100X.2009.00531.x>
- Williams L, Hale R, Cavnagaro T, Reich P, Lake PS (2011) Developing a vision for improved monitoring and reporting of riparian restoration projects: MDBA Riparian restoration experiment workshop, Melbourne, 16 November 2010. *Ecol Manage Restor* 12:11–16. <https://doi.org/10.1111/j.1442-8903.2011.00572.x>
- Wissmar RC, Beschta RL (1998) Restoration and management of riparian ecosystems: a catchment perspective. *Freshwater Biol* 40:571–585. <https://doi.org/10.1046/j.1365-2427.1998.00383.x>
- Withrow-Robinson BA, Bennett M, Ahrens GR (2011) A guide to riparian tree and shrub planting in the Willamette Valley: steps to success. https://ir.library.oregonstate.edu/concern/open_educational_resources/765371727
- Wortley L, Hero JM, Howes M (2013) Evaluating ecological restoration success: a review of the literature. *Restor Ecol* 21(5):537–543. <https://doi.org/10.1111/rec.12028>
- Yao Y, Fu B, Liu Y, Wang Y, Song S (2021) The contribution of ecosystem restoration to sustainable development goals in Asian drylands: a literature review. *Land Degradation Develop* 32(16):4472–4483. <https://doi.org/10.1002/ldr.4065>
- Zhao M, Geruo A, Zhang J, Velicogna I, Liang C, Li Z (2021) Ecological restoration impact on total terrestrial water storage. *Nat Sustain* 4(1):56–62. <https://doi.org/10.1038/s41893-020-00600-7>
- zu Ermgassen EK, Ayre B, Godar J, Lima MGB, Bauch S, Garrett R, Gardner T (2020). Using supply chain data to monitor zero deforestation commitments: an assessment of progress in the Brazilian soy sector. *Environ Res Lett* 15(3):035003. <https://doi.org/10.1088/1748-9326/ab6497>