Ecological restoration: An emerging eco-technology for sustainable environmental conservation

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ABSTRACT

Ecosystems on earth are frequently disturbed and damaged by natural (such as, tsunami, cyclone, floods, earthquake, wildfire, floods, storms, volcanic eruption, lighting, etc.) and anthropogenic activities. Disturbed or damaged ecosystems always pose great adverse environmental impacts for sustainable development. Therefore, ecological restoration has recently sprouted as a young and emerging branch of ecology to over come this problem, which aims to achieve complete structural, functional and self-maintaining biological integrity following by repairing and manipulating biological, geophysical and chemical frameworks using rehabilitation, enhancement, re-construction or re-creational processes. The present review attempted to draw a brief conceptual overview of ecological restoration – an emerging eco-technology for sustainable environmental conservation with some case studies in order to restore and conserve the damaged ecosystem. The principles of ecological restoration follow the underlying principles of ecosystem functions to reconstruct a facsimile of the natural community. Although many damaged ecosystems in different domains of the world have efficiently been restored by various organizations using ecological restoration process, most damaged ecosystems are still unattended and not restored probably due to lack of initiation of respective organizations and lack of funding supports with ecological, economic and social constraints. Therefore, using the involvement of local communities along with various organizations of ecosystem restoration, the damaged ecosystems can be repaired and conserve by applying the principles of ecological restoration in order to holistic and sustainable development.

1. Introduction

Natural disasters (such as tsunami, cyclone, floods, earthquake, wildfire, floods, storms, or volcanic eruption, lighting etc.), uncontrolled anthropogenic activities (such as population explosion, industrialization, urbanization, military activities, etc.) and various geogenic activities severely devastate and damage the different parts in the earth planet, which abruptly perturb and loss the ecosystems stability and functions. Consequently, it significantly poses negative impacts on ecosystems, biological diversity and peoples' livelihoods which adversely impacting the sustainable development of total environment. In many cases, the ecosystem generally cannot recover its predisturbance state or its historic developmental trajectory. As a result, damaged ecosystems pose adverse environmental impacts for sustainable development. It is a great challenge to the researcher and associated workers in order to recover or restore the frequently devastated, damaged or perturbed ecosystems into natural functioning condition.

In this respect, various ecological approaches, processes and technologies have been applied considering the ecological theory to overcome these undesirable situations and restore the different ecosystems, which are collectively known as "ecological restoration". Ecological restoration attempts to return an ecosystem to its historic trajectory. Therefore, the practice of ecological restoration has been identified as providing ideal experimental settings for tests of ecological theory and our ecological understanding (Young et al. 2005). It essentially outlines how it can provide enhanced biodiversity outcomes as well as improve human well-being in degraded landscapes by manipulating the ecological conditions. In this way, ecological restoration becomes a fundamental element of ecosystem management and its potential has not always been fully recognized. However, ecological restoration has recently recognized as a young and emerging branch of ecology to over come the problem of ecosystem damage. Therefore, the present review attempted to draw a brief conceptual overview of ecological restoration with some case studies for restoring and conserving the damaged ecosystem as well as for sustainable development of total environment.

2. Conceptual overview

The ecological restoration is an intentional activity that initiates or accelerates the recovery of an ecosystem with respect to its health, integrity and sustainability or in other way, it may simply be defined as the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed (SER 2004). However, it is a complex multidimensional ecological process of intervention applied for renewing and restoring the damaged or destroyed ecosystems by removing and modifying the specific damage causing disturbances. The restoration mechanism can transform the non-functional ecosystem to its functional stage by inserting and implanting different fundamental properties required for a typical functional ecosystem over a period. Both biotic and abiotic components (landscape, habitat, soil and water qualities, floral and faunal species) are considered as important characteristics in this respect. The various processes of ecosystem management are the example of ecological restoration as follows: erosion control, reforestation, usage of genetically local native species, removal of non-native species and weeds, revegetation of disturbed areas, daylighting streams, reintroduction of native species, as well as habitat, range improvement for targeted species, etc.

3. Historical overview

Restoration ecology is the young field of science associated with recovery of damaged ecosystem (Young et al. 2005). Though, ecological restoration has been practiced since long for about many hundreds or thousands years for ecological management (Anderson 2005) at least in its more applied forms, such as erosion control, reforestation, and habitat and range improvement, it is a newly emerging and unresolved issues in the field of ecology and has become a strong academic field attracting basic research recently. In late 80’s, the term restoration ecology was coined by John Aber and William Jordan at the University of Wisconsin – Madison (Jordan and Lubick 2012).

According to Bradshaw (1987), early ecologists recognized that the practice of ecological restoration could be an “acid test” of ecological theory. Conversely, Jordan et al. (1987) recognized that it is the highly manipulative nature of ecological restoration provided an ideal setting for hypothesis generation and testing in ecology. Recently, more critical and conceptual basis of ecological restoration and its emerging issues have extensively been considered and discussed by several scientists (Cairns and Heckman 1996; Hobbs and Norton 1996; Allen et al. 1997; Perrow and Davy 2002; Peterson and Lipcius 2003; Temperton et al. 2004; van Andel and Grootjans 2005; Aronson and van Andel 2005; Young et al. 2005). Jenkinson (2006) proposed about the database for effective ecological restoration that is conducive and highly supportive for developing the advanced plan for ecological restoration.

4. Goal of ecological restoration

Bradshaw (1987) advocated that an ecosystem may not be returned to its original state therefore, the restoration of an ecosystem in respect to functions of the ecosystem (especially ones that provide services to us) may be more valuable than its current configuration. Considering these concept, the prime goal of ecological restoration is to recover the damaged ecosystems into normal functional ecosystems by considering the following characteristics of an ecosystem:

- Natural physico-chemical properties of soil (land) and water
- Natural biodiversity (both flora and fauna) such as native species
- Especially conserving threatened or endangered species
- Restoring natural capital such as drinkable water or wildlife populations
- Mitigating climate change (e.g. through carbon sequestration) such as aforestation
- Aesthetic properties (Harris et al. 2006 ; Macdonald et al. 2002)

Some ecologists opined differences in how to set restoration goals and how to define their success since ecosystems are not static, but in a state of dynamic equilibrium. Some urge active restoration (e.g. eradicating invasive animals to allow the native ones to survive) and others who believe that protected areas should have the bare minimum of human interference.

5. Basic functional principle of ecological restoration

Ecosystems refer to dynamic interrelations of living and non-living components organized in self-regulating natural units with distinguished boundaries which functioning by complex exchanges of energy, nutrients and wastes in circular path way among the living and nonliving components (Odum 2004). The ecosystem stability is the dynamic equilibrium in terms of the exchanges of energy and nutrients which is known as functional stability of ecosystem. The ecosystem functions normally in equilibrium or stability state. If disturbances or perturbations occur from either internal or external sources which deviate the normal function of an ecosystem away from its current equilibrium state, then the ecosystem’s regulatory feedback (positive and negative) and redundancy mechanisms work to maintain the current or equilibrium state, or to bring the ecosystem to one of its other typical equilibrium states. Positive feedback is a deviation accelerating input and is necessary for growth and survival of organisms and population growth, whereas negative feedback is a deviation – counteracting input that prevents overgrowth of a population so that stability is maintained. Redundancy, a behaviour of ecosystem function where more than one species or component capable of performing a given function, is responsible for stability enhancement. In the ecosystem function, the degree of deviation caused by disturbances is referred to resistance stability, whereas the duration of persistence of disturbance that is time required for recovery of disturbed ecosystem is called as resilience stability (Fig. 1). The specific ecosystem functions those are apparently beneficial to human and other species are called as ecosystem services. In some cases of undesirable disturbances or perturbations, ecosystem losses self regulating functional ability and equilibrium state which leads to develop the damaged ecosystem in terms of its functions and unable to provide services naturally.

In view of the above central concept of ecosystem function, the basic functional principle of ecological restoration focuses on the recovery of functions of an ecosystem degraded, damaged or destroyed by natural and anthropogenic disturbances. To recover the functional sate of an ecosystem, the ecological restoration can be based on the following aspects (Fig. 1):

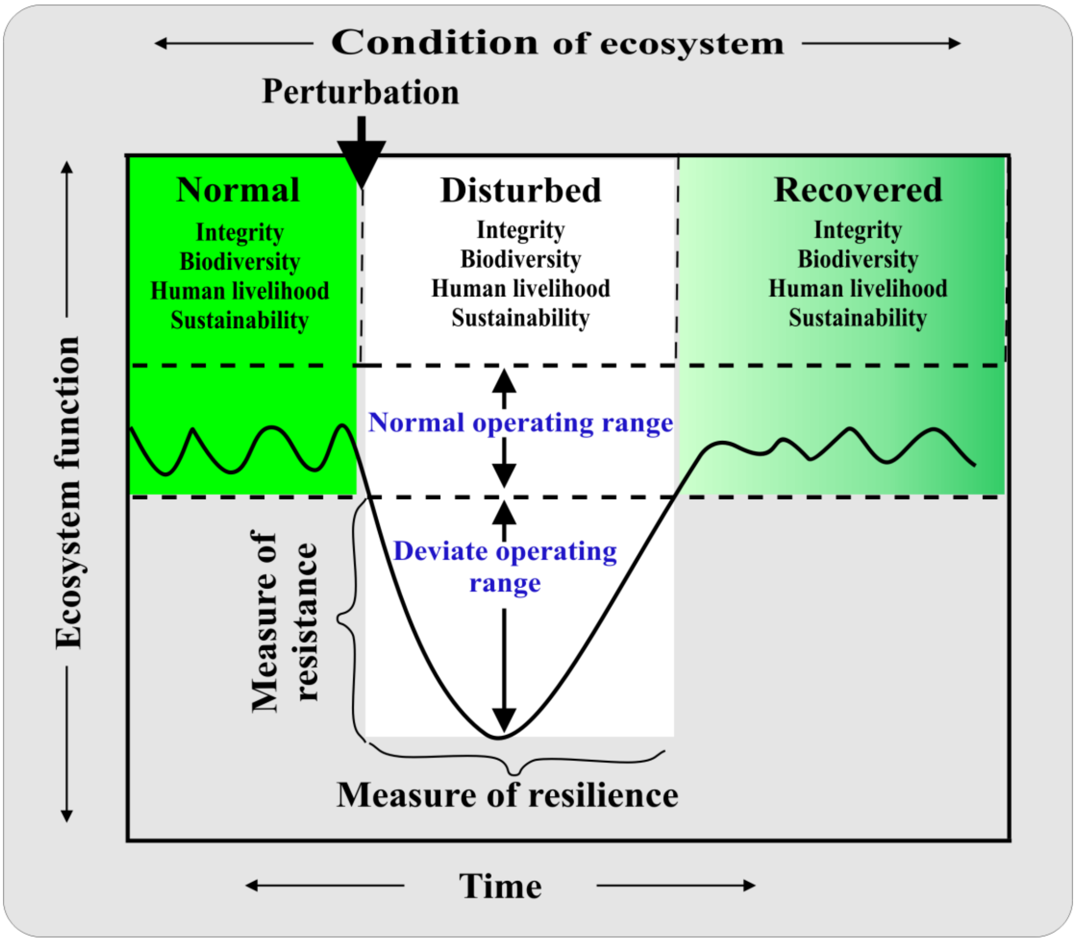
(1) **Health:** Functional processes, such as water filtration, sequestration of carbon dioxide, etc.
(2) **Integrity:** Species composition and community structure
(3) **Sustainability:** Resistance and resilience to disturbance

Additionally, there is now a growing realisation that many of the world's ecosystems have undergone significant degradation with negative impacts on biological diversity and peoples' livelihoods. Given that ecological restoration needs to address four elements which are critical to successful ecosystem management (Society for Ecological Restoration International and IUCN Commission on Ecosystem Management 2004). In this way, ecological restoration should (Fig. 1):

- Improve biodiversity conservation
- Improve human livelihoods
- Empower local people
- Improve ecosystem productivity

This means ecological restoration can be a primary component of conservation and sustainable developmental programmes.

Fig. 1 Ecosystem function in the conditions of normal, disturbed (functional deviation: resistance and resilient stabilities) and recovered of damaged ecosystem maintain)



5.1. Principles of good ecological restoration practice

Society for Ecological Restoration International and IUCN Commission on Ecosystem Management (2004) proposed that ecological restoration is a well-established practice in biodiversity conservation and ecosystem management, which is characterized in fourteen principles of good ecological restoration practice on the basis of experience gained over several decades. These principles of good ecological restoration practice are consistent with both the scope and intent of the Convention on Biological Diversity's Principles for the ecosystem approaches include (Society for Ecological Restoration International and IUCN Commission on Ecosystem Management 2004):

Ecosystems

- Incorporating biological and environmental spatial variation into the design.
- Allowing for linkages within the larger landscape.
- Emphasizing process repair over structural replacement.
- Allowing sufficient time for self-generating processes to resume.
- Treating the causes rather than the symptoms of degradation.
- Include monitoring protocols to allow for adaptive management.

Human systems

- Ensuring all stakeholders are fully aware of the full range of possible alternatives, opportunities, costs and benefits offered by restoration.
- Empowering all stakeholders, especially disenfranchised resource users.
- Engaging all relevant sectors of society and disciplines, including the displaced and powerless, in planning, implementation and monitoring.
- Involving relevant stakeholders in the definition of boundaries for restoration.
- Considering all forms of historical and current information, including scientific and indigenous and local knowledge, innovations and practices.
- Providing short-term benefits leading to the acceptance of longer-term objectives.
- Providing for the accrual of ecosystem goods and services.
- Striving towards economic viability.

6. Mechanism of ecological restoration

The restoration of an ecosystem is principally based on the recovery of ecosystem function. Since the basic functional principle of ecological restoration is same, the basic mechanism or process including guidelines for restoring the different damaged ecosystems is also similar. To restore a damaged ecosystem the sequential steps can be followed as briefly described below (Fig. 2). It has represented in slightly modified form of Society for Ecological Restoration International and IUCN Commission on Ecosystem Management (2004).

1. Determination of site
Firstly, the damaged ecosystem of the determined site is to be identified by investigation for restoration.

2. Assessment of site
It is one of the most important steps of restoration process. The ecological description of ecosystem types (terrestrial or aquatic), existing conditions (physico-chemical and biological), cause and factors of disturbances, etc. are the main assessment criteria which significantly required for planning the restoration process.

3. Development of goals
The goals of restoration of particular ecosystem are to be clearly determined with a clear rationale as to why restoration is needed. It easily helps to draw the clear plan of restoration using reference sites (nearby sites in natural condition) and/or consulting historical sources that describe the pre-disturbance community. It should include the specific target of restoration that is to be achieved in restoration process.

4. Development of plan
It is the most important steps of restoration process which effectively leads and manages the entire process of restoration. The time scale restoration plan determines the duration and costs required in restoring the damaged system. Additionally, it determines the functional strategies and identifies methods for stopping or reversing the disturbance essential for restoration process. In this respect, the following most important aspects are to be undertaken:

- An explanation of how the proposed restoration will integrate with the landscape and its flows of organisms and materials
- Explicit plans, schedules and budgets for site preparation, installation and post-installation activities, including a strategy for making prompt mid-course corrections
- Well-developed and explicitly stated performance standards, with monitoring protocols
- Strategies for long-term protection and maintenance of the restored ecosystem.

5. Execution of restoration plan
This is the practical and field-based important step of ecosystem restoration by implementing the specific plan designed for specific damaged ecosystem. It essentially includes the following sub steps:

- Removal/reduction of disturbance sources

It is the vital step of restoration, where, the source of disturbances must be identified and removed from the systems by applying physical, chemical and/or biological processes suitable in specific ecosystems. The important examples in removing disturbances are - remove toxic materials, remove causes of erosion, reduce overpopulation of species, eradicate invasive species, etc.

- Restoration of natural abiotic properties and processes

It is another important steps of ecosystem restoration, which associated with the restoration of natural process that is natural disturbance cycles of an ecosystems, such as - restore soil texture or chemistry, water regimes or water quality, habitat restoration, land scapping, rehabilitate substrates, restore tidal flow, flood or fire cycles, etc.

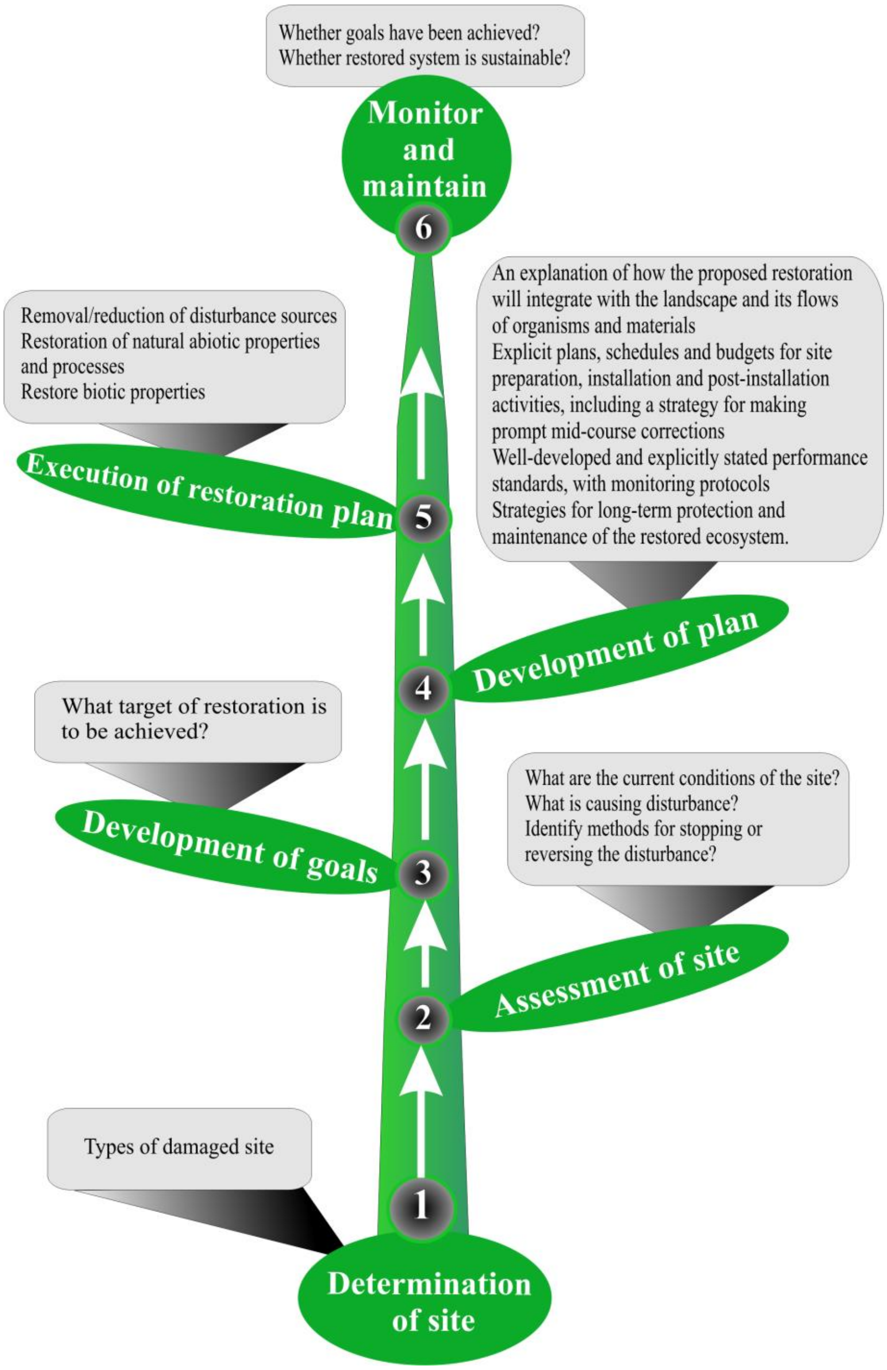
- Restoration of biotic properties

This step is inevitably and naturally associated with the establishment, promote and growth of biotic systems, such as - microbial, floral and faunal communities. The processes include afforestation, direct re-vegetation or seeding of a site using native species suited to local environmental conditions, bio-manipulation, conservation, eco-engineering, etc. Where possible a variety of sources within the local region should be used to ensure genetic diversity.

6. Monitor and maintain

This step is the management step of ecological restoration. Monitoring of restoration sites is critical to determine whether goals are being met. Ideally, restoration projects will eventually achieve a self-sustaining ecosystem without further need for intervention.

Fig. 2 Flow chart of ecological restoration mechanism representing six major steps (determination of site, assessment of site, development of goals, development of plan, execution of restoration plan, monitor and maintain)



7. Some case studies of ecological restoration

7.1. Fauna-focussed ecological restoration at Monjebup North, South Coast, Western Australia

Landscape/site

Monjebup North was purchased by Bush Heritage Australia (BHA) including the acquisition of a 400 ha area of cleared agricultural land with a zone of fragmentation between areas of remnant vegetation in the south of the property (Bush Heritage Australia's Monjebup Reserve) and the Corackerup Nature Reserve located to the north (http://www.seraustralasia.com/pages/casestudiesfaunawa.html). In 2011, Threshold Environmental Pty Ltd was commissioned by Bush Heritage Australia (BHA) to develop an Ecological Restoration.

Ecosystem assessment

Monjebup North's ecosystems are a semi-arid mixed mosaic of Open Shrub Mallee and Low Woodland vegetation associations.

Restoration goals

The goals of restoration were to significantly increase ecological connectivity within the local landscape. The outcomes of the project are conservation-focused, in particular the expansion of habitat access opportunities for the unique and diverse fauna and flora of the Fitz-Stirling region.

Ecological Restoration Plan

The plan was based on the analysis of soils, surrounding vegetation, and fauna habitat preferences. Seven main plant communities were identified for re-establishment according to soil type, including several types of Mallee, Open Woodlands, and a Swamp Woodland (Fig. 3).

Works undertaken an execution

In 2011, after planning and building a restoration map, the north-western corner (100ha) of Monjebup North was employed for restoration program by Threshold Environmental Pty Ltd in 2012. Several restoration techniques were applied as below:

- Direct seeding of 8 different seed mixes matched to soil type (species count more than 100 species)
- Planting seedlings of species across the whole site as well as in soil-specific "node" plantings
- Hand-broad seeding of 'rare' seed in patches of targeted soil types
- Development of habitat debris piles to encourage the return and occupancy of fauna, particularly ground-dwelling reptiles, marsupials, and native rodents
- On-site burning of serotinous species from the Proteacea family and subsequent in-situ seeding
- Chipping and mulching of select species for mechanical broadcast in contour graded 'seams'

Monitoring

A total of 21 long-term monitoring plots (15m x 15m) across the 8 vegetation systems seeded across the site in November 2012. The monitoring observed that all native species found within the plots, which enables identification of changes in germination, plant density and species composition over time. To date, 10 monitoring locations have been established, including 5 locations within the re-vegetated area and 5 reference sites in adjacent remnant vegetation.

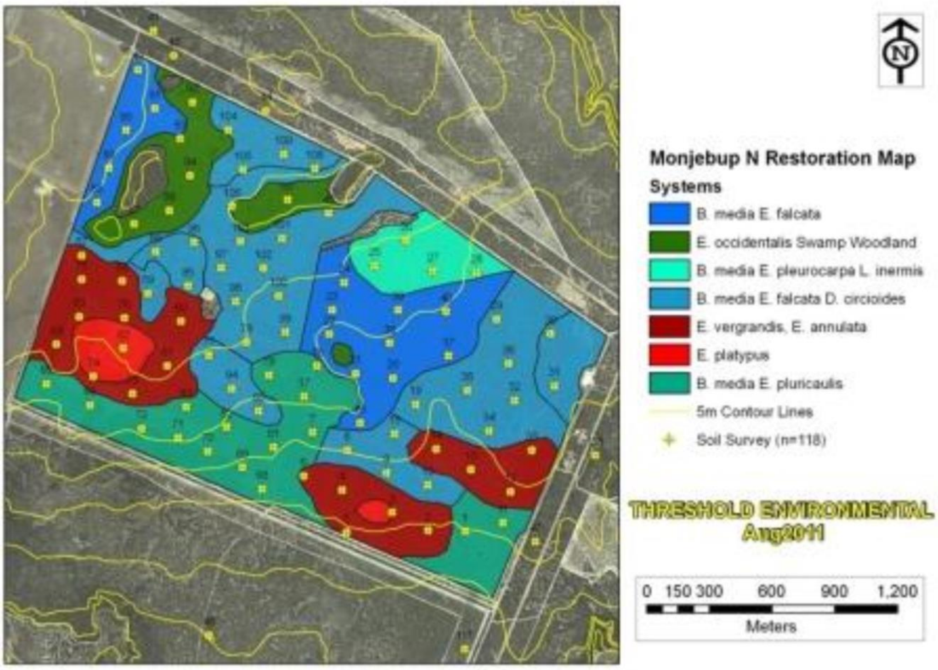


Fig. 3 The map is based on data of soil sampling and vegetation survey (http://www.seraustralasia.com/pages/casestudiesfaunawa.html)

Fig. 4 Natural view of La Mauricie National Park (http://www.pc.gc.ca/eng/progs/np-pn/re-er/ec-cs/ec-cs02.aspx)

7.2. Aquatic ecosystem restoration at La Mauricie National Park

Landscape/site

The landscape of La Mauricie National Park is of rolling hills, deep valleys and of the Lower Laurentian Mountains with characteristically heritage values of a network of lakes, ponds, streams and rivers resulting from the passage of glaciers (http://www.pc.gc.ca/eng/progs/np-pn/re-er/ec-cs/ec-cs02.aspx) (Fig. 4). The park also provides habitat for a diversity of aquatic and riparian plants and wildlife, some of which are rare or unique, including freshwater Arctic char and genetically unique brook trout populations.

Ecosystem disturbance - The forestry took place in the park. All useable lakes and streams were converted for the purpose of floating logs during that time. To raise water levels, dams and water diversions were built on most of the lakes, while streams were levelled and channelled to permit the passage of logs. Waterlogged wood, large logs or trunks accumulated on the bottom, at the mouths of lakes and along shores. The original habitat, riparian habitats, shorelines were damaged and modified by increasing water level.

The structure of the native aquatic community of the parks' lakes disrupted because of introducing the many species of fishes such as, smallmouth bass and white sucker, etc. over the years. The most significantly affected native species was the brook trout. In addition, the only population of Arctic char in the park, found in Lac Français, was threatened by the presence of introduced fish species and habitat degradation.

Restoration goals

The restoration goal of La Mauricie National Park was focused on

- Restoring water levels and a natural hydrological regime (variations in the water cycle) to the aquatic ecosystems affected by past forestry practices
- Improving riparian habitats by the removal of logs
- Lowering of lake levels as a result of dam removal
- Protecting the integrity of the park's unique brook trout and Arctic char populations
- Engaging the public involved developing a concept of recreational experience and harmonious discovery of these renewed aquatic ecosystems

Works undertaken and execution (Fig. 5 and 6)

- The water levels of six lakes were restored by removing dams, bridges and culverts.
- The riparian habitats of eight lakes were restored by removing accumulations of logs and debris from shorelines.
- The natural hydrological processes were restored by removing 13,000 14-foot hemlock logs from its different.
- The integrity of the fish communities of six lakes was improved by eliminating the introduced (alien) fish species.
- The recovered wood logs have been used in a variety of projects in the park including educational materials, artistic sculptures, etc.

Monitoring

To evaluate effectiveness of the restoration process, the monitoring program was developed over the years. Monitoring of fish species and other aquatic organisms was conducted both within and outside the park boundaries. The parameters, impact of dam dismantlement, lake depth, evolution of the shore areas, water quality, vegetation succession, fish populations, communities and spawning areas were monitored. The results obtained from the monitoring process were evaluated and reported regularly by publishing newsletters.

Fig. 5 Before log removal (a) After log removal (b) (http://www.pc.gc.ca/eng/progs/np-pn/re-er/ec-cs/ec-cs02.aspx)

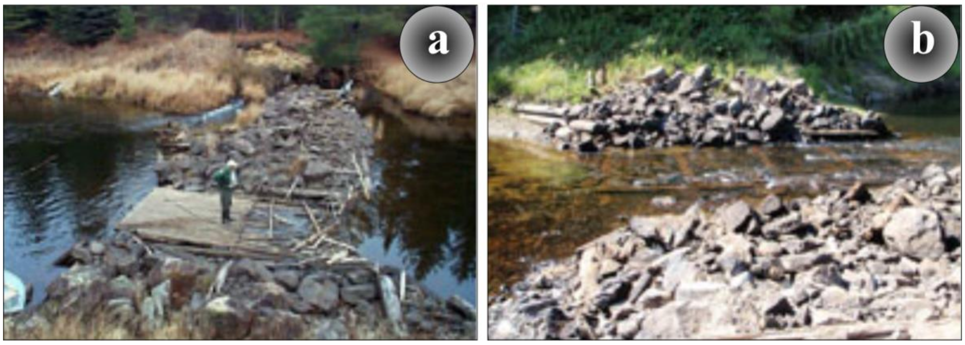


Fig. 6 Former logging transportation infrastructure before restoration (a) Former logging transportation infrastructure after restoration (b) (http://www.pc.gc.ca/eng/progs/np-pn/re-er/ec-cs/ec-cs02.aspx)

7.3. Mangrove restoration in Andhra Pradesh, India

The restoration landscape was mangrove wetlands on the east coast of India. A survey of the entire Godavari and Krishna mangroves was carried out in order to identify the degraded areas (http://www.globalrestorationnetwork.org/database/case-study/?id=60).

Goals

The goals of the restoration were as follows:

- To obtain greater commitment for the joint management of mangroves by the forest departments of these states in tandem with the local communities
- To enhance the capacity of the local communities to manage mangrove resources
  To reduce the pressure on the mangroves by demonstrating viable economic alternatives

Activities

Restoration began with the digging of canals to reduce salinity, facilitate tidal flushing, and drain stagnant water using a fishbone design in order to facilitate easy inflow and outflow of tidal water. The main canals were dug at an angle of 45º to the natural creek, and the side canals were dug at an angle of 30º to the main canal. The canals were dug in a trapezoidal shape in order to plant the saplings at the mid level of the canal and to receive tidal water without submerging.

Nursery-raised mangrove saplings were planted along the trapezoid-shaped canals in the degraded areas after a buffer period of three months. The eight-month-old saplings of *Avicennia marina*, *Avicennia officinalis* and *Excoecaria agallocha* were selected since these species tolerate a wide range of salinity and planted along the slopes of the canals (20 - 25 cm from the top) with a gap of 2 m. *Aegiceras corniculatum*, *Bruguiera gymnorrhiza*, *Rhizophora apiculata*, *Rhizophora mucronata* and *Xylocarpus moluccensis* were also planted in order to ensure genetic diversity.

Recovery

A total of 520 ha of degraded mangroves area were restored in this restoration. The bio-diversity of this mangrove area has been positively impacted by the restoration. The crab population and larger animals like otters population in the restored areas have increased due to the increased water regime. In addition to this, the bird population has shown an increase since the project began. Mangroves are now naturally regenerating with the hydrological improvements and further degradation of mangroves has stopped.

7.4. Post tsunami mangrove restoration in Sri Lanka

The mangrove forests and livelihoods of Bolgoda, Maduganga and Madampe in Sri Lanka were damaged by the Tsunami of 2004. Restoration of mangrove forests and livelihoods of Bolgoda was performed after Tsunami of 2004 (http://www.globalrestorationnetwork.org/).

The selected site was the lake areas of Bolgoda, Maduganga and Madampe in Sri Lanka along where 1,000 families from poor communities were also undertaken for restoration.

The aims of the restoration were to re-establish the mangrove and livelihoods of affected communities. A central goal is to improve the people's self-reliance, mitigate poverty effects, increase long-term access of people to sustainable use of natural resources and protect the local communities against potential disasters by the implementation of precautionary measures.

Fig. 7 (a) Damaged and (b) Restored ecosystems of acid mine (Quinton Towsnhip, Salem County, New Jersey)

The important activities of this restoration were the installation of mangrove nurseries, the re-plantation of damaged mangrove forests and the establishment and operation of regional education centres. The latter serves to educate and inform the local people of negative impacts from logging in forested areas and coral reef harvesting in order to reduce or avoid them as far as possible.

The monitoring programme observed and assessed that the mangrove plants was establishment and livelihood of poor communities was improved.

7.5. Mine Restoration (in Salem County, New Jersey)

The restoration site was located in Quinton Towsnhip, Salem County, New Jersey. It was an acid mine restoration project that also involved a population of a federally listed plant, swamp pink (*Helonias bullata*) (Fig. 7). The site was exposed by acid producing clays of mine. The pH of large soils areas and surface water of restoration site was less than 3 prior to restoration.

Prior to the restoration of the 59 acre mine, most of the swamp pink population was removed and maintained by Rutgers University during the restoration effort. The site was regarded as a more natural landscape, acid producing clays were buried and the soils amended with organic matter (spent mushroom compost) and other soil amendments, primarily lime prior to replanting. Wetland portions of the site were replanted with native species and the upland areas seeded with warm season grasses. The swamp pink individuals removed as well as those propagated while at Rutgers were replanted approximately 2.5 years after completion of restoration activities. The mine was acquired by the State of New Jersey to be part of a Wildlife Management Area.

8. Conclusion

The ecosystems in different domains of earth are frequently damaging in recent years by means of natural as well as anthropogenic activities which are a great challenge and thread to all forms of lives on earth. As a result the ecological restoration has been evolved as a potentially emerging field to restore the damaged environment. It is apparent that the areas of degraded ecosystems presently increasing in various parts of the world. Some of the damaged ecosystems can be restored easily because the degree of existing damage and disturbance is low, whereas those ecosystems are severely damaged by the strong or high degree of disturbance which are difficult, costly and takes long period for restoration. Further, many of these degraded systems are still being used with thread by people and many of these people are poor and with unawareness that may cause negative impacts on them. Therefore, the involvement of local human population is important in enhancing the restoration process by providing the basic knowledge of restoration. Though we may not fully succeed in eradicating the damage or disturbance causing factors in ecosystem restoration process but there is sufficient evidence from a variety of case studies for us to be optimistic. Ecological restoration essentially improves the biological diversity on degraded landscapes, increase the populations and distribution of rare and threatened species, enhance landscape connectivity, increase the availability of environmental goods and services, and contribute to the improvement of human well-being. Therefore, it clearly evidences that ecological restoration is a key element not only of conservation but also for sustainable development of world. However, many damaged ecosystems are still unattended and not restored probably due to lack of initiation of respective organizations and lack of funding supports with ecological, economic and social constraints. Furthermore, all damaged ecosystems should be considered for the ecological restoration in order to holistic and sustainable development worldwide.

References

Allen EB, Covington WW, Falk DA (1997) Developing the conceptual basis for restoration ecology. Restor. Ecol., 5:1275–1276

Anderson MK (2005) Tending the Wild: Native American knowledge and the management of California's natural resources. Berkeley: University of California Press. ISBN 0-520-23856-7

Aronson J, van Andel J (2005) Challenges for ecological theory. In: Restoration Ecology: The New Frontier (eds van Andel, J. & Aronson, J.). Blackwell Publishing, Oxford, pp. 223–233

Bradshaw AD (1987) Restoration: the acid test for ecology. In: Restoration Ecology: A Synthetic Approach to Ecological Research (eds Jordan, W.R., Gilpin, M.E. & Aber, J.D.). Cambridge University Press, Cambridge, UK, pp. 23–29

Cairns J, Heckman JR (1996) Restoration ecology: the state of an emerging field. Ann Rev Energy Environ 21:167–189

Harris JA, Hobbs RJ, Higgs E, Aronson J (2006) Ecological restoration and global climate change. Restoration Ecology 14(2):170–176

Hobbs RJ, Norton DA (1996) Towards a conceptual framework for restoration ecology. Restoration Ecology 4:93–110

http://www.globalrestorationnetwork.org/

http://www.globalrestorationnetwork.org/database/case-study/?id=60

http://www.pc.gc.ca/eng/progs/np-pn/re-er/ec-cs/ec-cs02.aspx

http://www.seraustralasia.com/pages/casestudiesfaunawa.html

Jenkinson RG, Barnas KA, Braatne JH, Bernhardt ES, Palmer MA, Allan JD (2006) The National River Restoration Science Synthesis. Stream Restoration Databases and Case Studies: A Guide to Information Resources and Their Utility in Advancing the Science and Practice of Restoration. Restoration Ecology 14(2):177–186

Jordan WR, Gilpin ME, Aber JD (1987) Restoration ecology: ecological restoration as a technique for basic research. In: Jordan WR, Gilpin ME, Aber JD (eds) Restoration Ecology: A Synthetic Approach to Ecological Research Cambridge University Press, Cambridge, pp. 3–22

Jordan WR, Lubick GM (2012) Making nature whole: a history of ecological restoration. Washington, D.C. Island Press. ISBN 9781597265126

MacDonald DW, Moorhouse TP, Enck JW (2002) The ecological context: a species population perspective. Cambridge University Press, Cambridge

Odum EP (2004) Fundamentals of Ecology. Saunders College Publishing, Philadelphia, USA

Perrow MP, Davy AJ (2002) Handbook of Ecological Restoration. Volume 1: Principles of Restoration. Cambridge University Press, NY, USA

Peterson CH, Lipcius RN (2003) Conceptual progress towards predicting quantitative ecosystem benefits of ecological restorations. Mar Ecol Progr Ser 264:297–307

SER (Society for Ecological Restoration) (2004) The SER Primer on Ecological Restoration, Version 2. Society for Ecological Restoration Science and Policy Working Group. http://www.ser.org/reading_resources.asp

Society for Ecological Restoration International Science & Policy Working Group (2004) The SER International Primer on Ecological Restoration. www.ser.org & Tucson: Society for Ecological Restoration International

Temperton VK, Hobbs RJ, Nuttle T, Halle S (2004) Assembly Rules and Restoration Ecology: Bridging the Gap between Theory and Practice. Island Press, Washington, DC

van Andel J, Grootjans AbP (2005) Concepts in restoration ecology. In: van Andel J, Aronson J (eds) Restoration Ecology: The New Frontier, Blackwell Publishing, Oxford, pp. 16–28

Young TP, Petersen DA, Clary JJ (2005) The ecology of restoration: historical links, emerging issues and unexplored realms. Ecology Letters 8:662–673