ISSN 1007-662X (Print)
ISSN 1993-0607 (Online)
CODEN JFREAT

Journal of Forestry Research

2014

Vol. 25 No. 1

Northeast Forestry University

Ecological Society of China

Springer

Journal of Forestry Research (2014) 25(1): 21–28
DOI 10.1007/s11676-014-0429-2

REVIEW ARTICLE

Biodiversity and ecological assessments of Indian sacred groves

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Received: 2012-02-18; Accepted: 2012-03-29

Abstract: Sacred groves are patches of forests preserved for their spiritual and religious significance. The practice gained relevance with the spread of agriculture that caused large-scale deforestation affecting biodiversity and watersheds. Sacred groves may lose their prominence nowadays, but are still relevant in Indian rural landscapes inhabited by traditional communities. The recent rise of interest in this tradition encouraged scientific study that despite its pan-Indian distribution, focused on India's northeast, Western Ghats and east coast either for their global/regional importance or unique ecosystems. Most studies focused on flora, mainly angiosperms, and the faunal studies concentrated on vertebrates while lower life forms were grossly neglected. Studies on ecosystem functioning are few although observations are available. Most studies attributed watershed protection values to sacred groves but hardly highlighted hydrological process or water yield in comparison with other land use types. The grove studies require diversification from a stereotyped path and must move towards creating credible scientific foundations for conservation. Documentation should continue in unexplored areas but more work is needed on basic ecological functions and ecosystem dynamics to strengthen planning for scientifically sound sacred grove management.

Keywords: biodiversity, conservation, ecosystem service, endemics, sacred grove

Introduction

Sacred groves are segments of the landscape, containing trees and other forms of life and geographical features, that are delimited and protected by human societies because it is believed that retaining them in a relatively undisturbed state is an expression of an important relationship with the divine or with nature (Hughes and Chandran 1998). The role of these natural sacred sites is attracting increasing interest in international organizations such as UNESCO and the World Wide Fund for Nature. International Union for Conservation of Nature and Natural Resources (IUCN) treats sacred groves under sacred natural sites (SNS) which can be clarified as "natural areas of special spiritual significance to peoples and communities. They include natural areas recognized as sacred by indigenous and traditional peoples as well as natural areas recognized by institutionalized religions or faiths as places for worship and remembrance" (Oviedo et al. 2005).

Sacred groves *per se*, as protected patches of natural vegetation, assumed increasing importance with the arrival of agriculture. Rapid spread of agriculture and pastoralism necessitated clearance of vast stretches of primeval forests. The fear of offending the gods of nature and the adverse consequences of forest clearance in the form of soil erosion, drying of watersheds, impoverishment of biodiversity, changes in microclimatic conditions and pest pressures propelled the emergence of sacred grove-centered worship. Groves existed in the past or continue to exist today in many parts of the world, among people with many religions and forms of social and economic organization. Groves were preserved in the name of gods in ancient Asia, Africa, Europe, America and Austro-pacific region (Hughes and Chandran 1998).

Throughout history, many people customarily respected sacred groves. These were sections of forest where spiritual beings were believed to reside, and where ordinary activities such as tree felling, gathering of wood, plants and leaves, hunting fishing, grazing of domestic animals, lowing or harvesting of crops, and building ordinary dwellings were prohibited (Hughes and Swan 1986).

Sacred grove culture in India has pre-Vedic roots. The Vedic people personified elemental forces of nature as divinities but had no association with sacred grove culture of non-Vedic inhabitants (Chandran 2005). The pan-Indian distribution of groves is a subject of great interest to biologists, social scientists, anthropologists and policy makers because groves represent a variety of ecosystems, social and ethnic identities, management regimes, legal tenures, and cultural traditions. Groves in Indian states/regions number in the hundreds or thousands (Malhotra et al. 2001).

The online version is available at http://www.springerlink.com

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The scientific community today recognizes this tradition as one of the tenets of sustainable use of natural resources. The spiritual ties that humans established from ancient times with prime patches of forests ensured not only the long-term subsistence interest of local people but also protected the dynamics of local ecosystems.

The term "biodiversity" is defined as "the variability among living organisms from all sources, including terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems." (World Conservation Union 2001). Biodiversity study can be of many types, including inventory and documentation, diversity assessment, population status and ecology, management and threat. Biodiversity can also be linked with ecosystem dynamics, social-cultural-religious practices and ethnic identity. Our focus is on biodiversity studies from the biologist's perspective.

Biological studies of the sacred groves of India got a fillip with the pioneering work of Gadgil and Vartak (1975, 1976, 1980). For the first time the groves were studied in a holistic way encompassing biological, ecological and socio-cultural perspectives. In subsequent years, a huge volume of literature was produced on sacred groves and natural sacred sites encompassing various facets. However, literature on biodiversity is to some extent limited because the regional or local characteristics of groves are often of interest to limited audiences. Moreover, check lists of flora and fauna that are available for many groves list species inventories but provide little detailed understanding of biodiversity. Therefore, for comprehensive review one must depend on publications that are widely circulated through public/scientific communication systems and that follow scientific and logical criteria.

There are some interesting reviews on sacred groves of India, emphasizing biodiversity conservation (especially on floral aspects), natural resource management, cultural and conservation values but details of biodiversity and ecology are not yet covered (Chandrashekhara et al. 2011; Khan 2008; Kushalappa et al. 2005; Ormsby and Bhagwat 2010). In this review, we compiled all major publications on biodiversity assessment of sacred groves in India. We focused on the roles of groves in rare and/or endemic species conservation, economic potential and ecological processes. Our review is based on Indian groves but discussion of the biological and ecological importance of these relic forest fragments is pertinent for any region of the world. Along with well designed scientific studies, general observations have also been recorded especially on ecological issues. This review will hopefully prompt researchers to explore new areas in sacred grove studies and attempt to describe functional aspects and ecosystem services, using well-designed, locality-specific methods.

Study method

We searched using internet-based search engines, databases on scientific literature (e.g. science direct, scopus, ISI) and leading ecology and conservation journals with keywords, including "sacred grove biodiversity", "ecology of sacred grove", "sacred grove India". We restricted ourselves to quantitative studies and documented observations on grove biodiversity and ecology. As the ecology and biodiversity of sacred groves are regional and ecosystem specific we also retrieved local information where possible. We also considered a few qualitative and inventory studies because of the subject or region they covered.

We shortlisted 75 studies based on their scientific merit, subject and availability. Studies were arranged according to area of work, year, problems/issues addressed and major findings. Details of our findings are followed below.

Result

Grove studies were concentrated geographically in three regions, Western Ghats, northeast India (i.e. Indian Himalayan states) and Eastern Ghats-Coromandel Coast. Fewer studies addressed the central Indian plateau, Gangetic plain, western Himalaya and western desert (Fig.1). Although sacred groves are distributed throughout the country in every type of ecosystem, the predominance of studies reporting on only three geographic areas clearly represent researcher preference. The main reason for study of groves in the Western Ghats and northeast India is perhaps their hotspot status and rapid land use change which draws attention at national and international levels. On the other hand, studies from the Eastern Ghats-Coromandel Coast region emphasize a unique vegetation type (i.e. tropical dry evergreen forests) preserved under sacred grove tradition (Fig. 2). The idea of considering sacred groves as natural resource management systems was conceptualised in the mid 1970s and gradually led to studies of natural resources, life-forms, and management regimes. Early studies were mainly inventories to document presence of flora and fauna species. During the mid 1990s attention shifted to ecological issues such as population studies, community structure and composition, and anthropogenic impact, and this trend continues today.

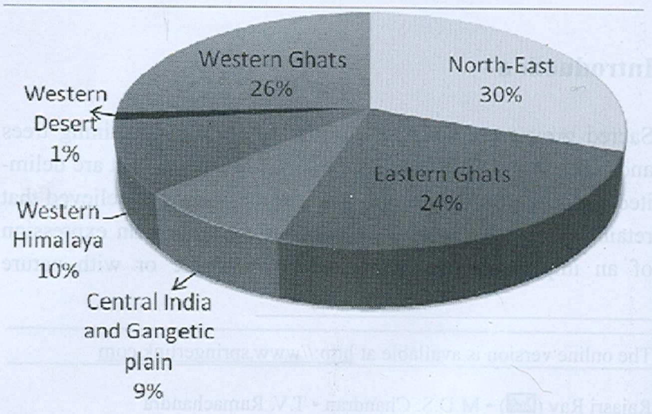

Fig. 1. Distribution of biodiversity and ecological studies in biogeographic regions of India

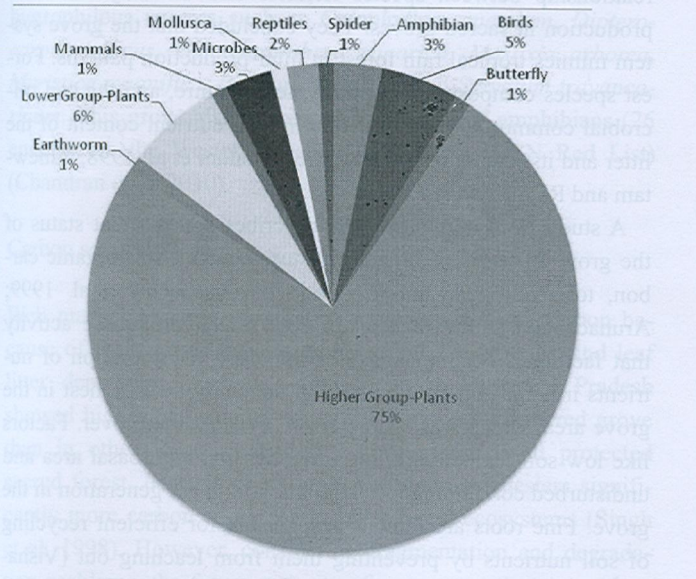

Fig. 2. Taxonomic groups addressed by sacred grove studies

Biodiversity assessment

Plant diversity of sacred groves

Sacred groves, despite their fragmentation and isolation, are repositories of rare species in comparison to adjoining landscape elements (Bhagwat et al. 2005; Bhakat 2004; Khan et al. 2008, Rao et al. 2011). Flora inventories of groves include species composition and richness, dominance, distribution, rarity and endemism (Khumbongmayum et al. 2005a; Parthasarathy and Karthikeyan 1997; Pushpangadan et al. 1998; Upadhaya et al. 2003; Vartak and Kumbhojkar 1984).

Groves represent diverse ecosystems with widely varying species composition (Table 1). As parts of relic vegetation types and under community-based conservation management or forest department jurisdiction, groves often act as refugia for rare, threatened and endemic species (Jamir and Pandey 2003; Sukumaran et al. 2008; Rao et al. 2011; Ray 2011). Smaller groves, however, are subjected to isolation and higher human pressures, and tend to have a greater mix of secondary and invasive species of plants (Induchoodan 1996; Ramanujam and Kadamban 2001, Chandrashekhara et al. 2011). Short-term studies reported the stable and regenerating nature of plant communities based on the abundance of seedlings and saplings although long-term assessments are rare (Boraiah et al. 2001; Chandrashekara and Shankar 1998; Khumbongmayum et al. 2006; Laloo et al. 2006; Mishra et al. 2005; Rao et al. 1997). Species documentation and threat assessment were primary topics of study and few reports addressed endemic or rare species population status, ecology, physiology or genetics. The limited range of study impedes understanding of the role of groves in support of vulnerable species (Chaithra et al. 2005; Ray 2011).

Table 1. Ecosystems and characteristic flora represented by Indian Sacred groves

Ecosystem	Representative flora	Region (States)	Reference
Wet evergreen, semi-evergreen forest	*Dipterocarpus indicus, Mesua ferrea, Vateria indica*	Western Ghats (Karnataka, Kerala)	Chandran et al. (2010), Jayarajan (2004)
Dry evergreen forest	*Tricalysia sphaerocarpa, Pterospermum canescens*	Eastern Ghats-Coromandal Coast (Tamil Nadu)	Parthasarathy and Karthikeyan 1997 Ramanujam and Kadamban 2001
Sub tropical wet hill forest	*Quercus, Castanopsis, Lithocarpus, Michilus, Neolitsea, Schima, Camellia*	Eastern Himalaya (Meghalaya)	Jamir et al. 2003, Jamir et al.2006,
Swamp forest	*Myristica fatua var. magnifica, Gymnocranthera canarica, Syzygium mundagam, Syzygium travancoricum*	Western Ghats (Karnataka, Kerala)	Chandran et al. 2010, Vidyasagaran et al. 2005, Jayarajan 2004
Mangrove	*Bruguiera cylindrica, Acrostichum aureum, Excoecaria agallocha, Sonneratia alba*	Western coast (Kerala, Goa)	Jayarajan 2004, Untwale et al. 1998
Desert	*Acacia nilotica, Acacia senegal, Prosopis juliflora*	Indian desert (Rajasthan)	Jha et al. 1998

Lower plants

Biodiversity studies dealt mainly with higher plant species, though some groves harbored interesting lower plants. Pteridophytes were reported from sacred groves at Kanyakumari, Tamil Nadu (Sukumaran et al. 2009). Similarly, moss, lichen and fungal communities were reported from some areas (Manju et al. 2008; Kayang 2006; Nayaka 2004). Brown et al. (2006) studied 25 sacred groves of Western Ghats for macrofungi and reported distinct assemblages of macrofungi from these sites. The abundance of leaf litter and dead wood in the sacred groves are responsible for the unique assemblage of these decomposer fungi.

Faunal study

Groves, especially those in humanized landscapes, act as local refugia for fauna. Although the small size of the groves does not permit large fauna to stay, suitable microclimate allows numerous medium to small species to reside. Studies emphasized vertebrates, including discovery of a new frog species (Das and Chanda 1997; Das et al. 2010), avifauna richness (Ahmed 2004; Chandran and Gadgil 1998; Deb 1997; Sashikumar 2005), fauna species presence (Jha et al 1998; Jayarajan 2004). Among invertebrates, earthworms, butterflies, spiders, and mollusks were studied but others were completely untouched (Sinha et al. 2003; Jayarajan 2004; Mumbrekar and Madhyastha 2006).

Economic importance

Plant diversity studies often referred to the economic and subsistence values of sacred groves. Although cutting of trees is typically banned in sacred groves, non-timber forest products (NTFPs) were traditionally harvested, especially from larger sacred groves. The forests of the *kans* of Uttara Kannada and Shimoga included various edible fruits and seeds, palm toddy, palm starch, and medicinal plants (Chandran and Gadgil 1998; Dewar 2008). In fact, a cornucopia of medicinal plants is reported from the sacred groves in different parts of India in various studies. These plants are important in the primary health care of rural masses, and sometimes, as in the case of forest dwellers, their only source for medication (Boraiah et al. 2003; Anthwal et al. 2006; Laloo et al. 2006; Rajendran and Agarwal 2007, Sukumaran et al 2010). Similarly, groves as a resource for NTFPs have been established at various levels (Negi 2005; Sukumaran et al. 2008; Ulman and Mokat 2008).

Ecosystem functions and services

Ecological functions and dynamics of local ecosystems surrounding sacred groves received less research attention than did biodiversity assessment. These aspects are important for grove management and conservation especially in humanized landscapes. Obviously, the area of a sacred grove plays a major role in ecosystem functioning and services. A large and intact grove represents a healthy forest ecosystem that provides valuable ecological services such as soil, water and biodiversity conservation, nutrient cycling and temperature regulation. Small fragmented groves provide lesser values of these services. However, at local levels even small groves can play important ecological roles in pollination, seed dispersal and corridor provision for animals, and these issues require detailed analysis (Ray and Ramachandra 2010).

Soil conservation and nutrient cycling

The undisturbed vegetation cover of the grove plays a significant role in soil conservation. When litter accumulates, organic material degrades, which returns nutrients to the soil and to the standing biomass. In the process, many microorganisms, invertebrates, and fungi will flourish, and species not indigenous to ploughed fields and secondary forests can survive in the groves (Hughes and Chandran 1998). Rajendraprasad (1995) observed higher porosity and low bulk density for the soils of groves compared to the soils of nearby areas in Kerala. The rich cover of leaf litter, humus and dense networks of roots are important in preventing erosion and fostering soil building. Water seeping out of sacred groves onto surrounding cultivated lands is considered nutrient rich by village communities (Induchoodan 1996). Yet studies are needed to substantiate such beliefs.

Nutrient cycling was addressed in detail in some studies of grove systems. Rajendraprasad et al. (2000) documented a linear relationship between species richness and diversity and litter production in sacred groves. They concluded that the grove system mimics tropical rain forest in litter production patterns. Forest species composition, humidity, temperature, and the soil microbial community usually determine the nutrient content of the litter and its release in the soil (Arunachalam et al. 1998; Khiewtam and Ramakrishnan 1993).

A study from northeast India describes soil nutrient status of the grove in terms of higher moisture content, soil organic carbon, total nitrogen, and C/N ratio (Arunachalam et al. 1999; Arunachalam and Arunachalam 2000). Dehydrogenase activity that facilitates decomposition of litter and incorporation of nutrients into the soil, as observed in the study, was highest in the grove area, which was characterized by rich litter cover. Factors like low soil temperature, high tree density, high basal area and undisturbed condition govern the fine root mass generation in the grove. Fine roots are directly responsible for efficient recycling of soil nutrients by preventing them from leaching out (Vishalakshi 1994). The role of groves in maintaining tropical ecosystems through leaf litter and root dynamics in Cherrapunji, Meghalaya showed that the development and stability of a fragile rainforest ecosystem over a nutrient deficient calcareous landscape was supported by efficient nutrient cycling through leaf litter and networks of fine roots developed on the soil surface (Khiewtam and Ramakrishnan 1993).

Water conservation

The role of sacred groves in protection of perennial water sources is widely known. This might be the single most widely documented ecological function reported from many parts of India. In Meghalaya, well preserved groves efficiently reduce the erosive power of runoff water thus preventing soil erosion and nutrient wash out (Khiewtam and Ramakrishnan 1993). The Lum Shyllong-Nongkrim sacred groves in Meghalaya are the source of as many as eight streams that supply water to Shillong, the capital of Meghalaya (Sethi and Viswanath 2003). In the Himalayan region, sacred groves located on steep and rugged slopes towards ridges regulated water flow and sedimentation (Singh et al. 1998).

In the Western Ghats, most sacred groves are associated with perennial streams that are important water resources for neighbouring communities throughout the year (Chandran and Hughes 1997; Godbole and Sarnaik 2004; Waghchaure et al. 2006). Perhaps the most significant contribution of sacred grove in water conservation could be witnessed in Rajasthan, where water bodies associated with orans served as lifelines for local inhabitants and livestock. Jharan sacred grove in Jhalawar ensured the water supply to Jhalawar city and protected the catchment of the stream from siltation (Pandey 2000).

The water retention capacity of groves favours the occurrence of more sensitive, hygrophilous endemic species in some groves. If we look at the distribution of endemic species in the Western Ghats, the sacred groves of Central Western Ghats form the northernmost limits for most of them. The Kathalekan of Siddapur taluk, in Uttara Kannada, a sacred grove of the pre-colonial past, is notable for the swampy forests sheltering a community of rare hygrophilous species such as *Calophyllum apetalum*, *Dipterocarpus indicus*, *Gymnacranthera canarica*, *Mastixia arborea*, *Myristica magnifica*, *Pinanga dicksonii*, and *Syzygium travancoricum*. This grove also supported 35 species of amphibians (26 endemic to the Western Ghats, 11 listed by IUCN Red List) (Chandran et al. 2010).

Carbon sequestration

Well managed sacred groves can serve as sinks for carbon because of their varied species composition, tree density and leaf litter deposition. Nagoni sacred forest in Himachal Pradesh showed higher percentages of soil carbon stock in sacred grove than in other forest ecosystems. Furthermore, well protected sacred forest, because of its higher biomass, sequesters significantly more carbon compared to other forest ecosystems (Singh et al. 1998). However, considering fragmentation and degradation problems, the future capacity of groves to sequester carbon should be quantified so that steps can be taken to protect and restore sacred groves as local mitigation measures for climate change.

Sacred grove and landscape heterogeneity

Sacred grove is not an isolated system. By their presence amidst a mosaic of landscape elements such as utility forests, agricultural fields, grazing lands, plantations, human settlements these relic forest patches enhance landscape heterogeneity and biodiversity. Studies reported to date often dealt with groves as single entities for assessment of biodiversity and ecology without emphasizing landscape level importance.

In Kodagu region of Karnataka, sacred groves in combination with the tree cover in coffee plantations played an important role in maintaining forest bird diversity. They also provided diverse microclimatic conditions that nurtured several distinct macrofungal species not found in forest reserve or coffee plantation (Bhagwat et al. 2005). Ambinakudige and Satish (2009) compared coffee plantations with sacred groves and found that groves contributed more in landscape level biodiversity. Page et al. (2010) reported similar findings for life forms such as epiphytes, shrubs and lianas. Ray (2011) recorded the endemic tree diversity in agricultural landscapes and found that groves act as local shelters for regional endemics.

Fragmentation of groves often affects seed dispersal, regeneration and genetic diversity of rare plants, ultimately causing declines in plant populations. The availability of pollinators and seed dispersers is adversely affected due to fragmentation causing declines in mutualistic relationships between plants and animals. Reports from Konkan and Kodagu regions highlighted that larger groves had better recruitment potential (both seedling density and seedling survival) than did smaller groves for species including *Antiaris toxicaria*, *Strychnos nux-vomica*, *Artocarpus hirsutus* and *Canarium strictum*. However, apart from grove size, habitat quality, connectivity and population of seed dispersers may have roles in plant population dynamics (Punde 2007; Tambat et al. 2005). Studies on genetic diversity of *Litsea floribunda* (Western Ghats endemic) and *Mangifera indica* in sacred groves reported that smaller groves harbor higher variability for *L. floribunda,* whereas for *M. indica* small and large groves showed no difference, signifying the importance of smaller groves for conservation (Chaithra et al. 2005).

Disturbance over biodiversity

Biodiversity studies reported disturbances in groves which were mostly anthropogenic. Disturbances were categorized into i) land use change (e.g. deforestation, land conversion, fragmentation, encroachment), ii) change in species composition, both planned and accidental (e.g. plantation, disturbance due to land use change, unplanned restoration activities etc.), iii) developmental activities in and around the grove area and iv) changes in social norms, cultural and religious practices.

Grove biodiversity has been affected in many ways due to these threats. Land use change causes reduction in grove area, thus exposing interior grove biota to adverse surrounding environments. Many sensitive species were affected and lost, whereas, invasive species like *Lantana camara, Chromolaena odorata* become established in the grove area (Mishra et al. 2004; Rao et al. 2011; Chandrashekhara et al. 2011).

Original species composition of the groves has often been changed due to human intervention (both planned and accidental). Plantation (e.g. *Acacia, Eucalyptus*), horticulture requirement (*Hopea ponga*), unplanned restoration activities (establishment of exotic plants in the name of restoration) and disturbance in the landscape often introduce new species into the grove system that affect grove biota and impact the ecological function of the area (Gokhlae 2005).

Decline of regeneration potential is a serious problem for future survival of grove species. Often developmental activities, grazing, unrestricted entry, and resource exploitation lead to damage of understory flora (i.e. seedlings and saplings) thus causing uncertainty for future local survival of the species. The situation is particularly alarming for endemics and rare species because of their very restricted distributions due to high spatio-temporal sensitivity (Barik et al. 1996; Ray 2011).

Management of groves is very much related to the social and cultural-religious norms of nearby communities. Studies have pointed out that ecological profiles can be used as indicators of grove management. A community managed, well maintained grove might have higher stem density, higher basal area and good regeneration potential. In contrast, disturbed groves were often dominated by heliophilic open space species (Chandrashekhara and Shankar 1998; Chandrashekhara 2011; Gokhale 2005; Upadhaya et al. 2004).

Future research directions

The pan-Indian distribution and abundance of sacred groves in different ecosystems justify the continuation of inventory and documentation work. On the other hand, biodiversity study requires new orientation. Emphasis should be placed on ecosystem dynamics and ecological functions to understand the underlying natural factors responsible for maintaining biodiversity. Following are the areas which need attention in this regard.

Ecosystem functioning

Water conservation, microclimate control, carbon sequestration, plant-animal interaction (e.g. pollination and seed dispersal) are some of the principal ecological functions which keep the life cycle processes in rhythm. Without proper understanding of these factors it is difficult to formulate any effective conservation strategy for grove biodiversity.

Landscape dynamics and its conservation importance

To date, all conservation activities are grove oriented in that they consider a grove as a single entity. Groves that are present in the humanized landscape may require attention from a landscape view point. Being a part of heterogeneous landscapes, grove biota is dependent on the surrounding land use types at different life cycle phases. Activities such as pollination, seed dispersal, germination among plants, and foraging and nesting among animals usually occur at broader spatial scales depending on availability of suitable life supporting habitats. Except for the few habitat-specialist species, most organisms successfully exploit a variety of landscape elements and depend on landscape-level heterogeneity. Therefore, any drastic change in the landscape can affect life cycle of organisms although the supporting grove area remains intact. Activities like pesticide applications on farmlands (may affect bee and insect populations), diversion of water bodies (affecting moisture sensitive plants and animals), developmental activities (affecting food resource for the animals) affect the entire ecological dynamics directly or indirectly.

Landscape level conservation involves multiple stakeholders at different levels with varied interests. It requires community involvement at larger scale and effective management strategy for sustainable livelihood development with an aim to biodiversity conservation. However, due to inadequate knowledge on complex ecological processes and complex socio-economic scenario, the landscape level approach is still in its infancy.

Impact of fragmentation over the grove system

Present day groves are the remnants of past forests. They are isolated forest patches surrounded by various land use elements and subject to disturbances at various levels. Once the grove becomes fragmented, adverse conditions generate spontaneously e.g. edge effect, habitat reduction, changes in microclimate, and soil compaction and these affect grove biota in many ways. Studies are yet to be done to understand the impact of fragmentation on biodiversity and to design mitigation measures.

Ecosystem services and valuation

Ecosystem services are the benefits we receive in the form of tangible and non-tangible goods, from complex ecological functions of nature. Biodiversity is the key factor behind these services. It is the presence of diverse organisms and their complex interactions, that yield products and services that are beneficial for mankind. Among the major four types of services (viz., provisioning, regulatory, supporting and cultural), only provisioning service can be judged using a market framework. Although evaluation and quantification of all services is not possible at this moment, but attempts could be made to assess values of the measurable goods and services whenever possible. Because groves are a part of rural socio-economic life, it is important to evaluate their services using common terms so that local inhabitants can join in the conservation activity to represent their own interests.

Acknowledgement

The authors acknowledge the funding from Indian Institute of Science for pursuing the research work.

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