A review of the ecological functions of reed bamboo, genus ochlandra in the Western Ghats of India: Implications for sustainable conservation

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Review Article

A review of the ecological functions of reed bamboo, genus *Ochlandra* in the Western Ghats of India: Implications for sustainable conservation

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Abstract
Reeds are a tall, thin, shrubby, highly productive grass of the Poaceae family, and have a worldwide distribution except for in Antarctica. Temperate reed species include *Phragmites australis* (Cav.) Trin. ex Steud., *Arundo donax* L., *Phalaris arundinacea* L. Tropical reeds include bamboo genus *Ochlandra* and are endemic to the Western Ghats of India as well as to Sri Lanka. Reeds are an important component of the forest ecosystem, providing numerous ecosystem services which help to maintain forest stability. They are a keystone species and serve as an important food source for many animals. Reed biomass is widely used for solid biofuel production and for mitigating greenhouse gas emissions. They are an excellent sink for carbon sequestration and the absorption of point-source pollution from the waterbeds. Reed bamboos have been considered as the most important non-timber forest product (NTFPs) for the subsistence and support of the economically weaker strata of the society. Owing to ever increasing demand, coupled with unscientific management practices, there has been a gradual depletion of reed resources over the years. The reed bamboo biomass of the Western Ghats, in particular, has been severely depleted, and there is an urgent need for effective conservation and proper scientific management to ensure its viability and long-term survival. This review summarizes the versatility and importance of reeds in terms of ecological benefits, carbon sequestration ability, soil and water management potential and ecosystem services, with particular reference to the endemic reed bamboo resources of the Western Ghats of India.

Key words: Reed bamboos, keystone species, ecosystem services, *Ochlandra,* resource depletion, conservation, conservation management

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Introduction

Reeds are a tall, thin, shrubby, highly productive grass belonging to the Poaceae family. They are found all over the world except in Antarctica, but their core distribution area is Europe, the Middle East and America [1]. They are a characteristic of wetland regions [2]. Common reed species of temperate regions include *Phragmites australis, Arundo donax*, *Phalaris arundinacea.* The endemic reed bamboo, genus *Ochlandra,* of the Western Ghats, India is the only species confined to the tropical zones. Reed bamboos are one of the most ecologically and economically exploited grass species in this region.

Today, reed is considered a valuable raw material with multiple uses. An increase in human population density and the economic development of many countries has given rise to a corresponding increase in the demand for reed resources. The drastic increase in the demand of energy worldwide and the predominant use of fossil fuel resources with their related environmental consequences, has led to a growing market for alternative, renewable sources of energy. Biomass is one of the most important sustainable resources [3], and reed biomass, which has a low bulk density (0.02- 0.06 gcm^{-3}), is widely used for solid biofuel production [4, 5]. Reed biomass is also a rich source of cellulose and hemicelluloses [6], which acts as a substitute for fossil feedstock and can be used as an alternative to petroleum based fuels [7]. It thus has an important role to play in mitigating greenhouse gas (GHG) emissions [5]. Since most reeds inhabit wetlands, the exploitation of reed resources offers the dual advantages of increased yields and the enhancement of the water purification function of the wetlands. Reed can be utilised both as an energy source and as an industrial raw material and traditionally harvest for roofing material [8].

Phragmites australis is the common Poaceae reed, with more than 100 genera represented in the northeastern United States [9]. Its closest relative, *Arundo donax* L., is a giant reed of the Mediterranean region. Two biotypes of *Phragmites* have been found in South Dakota, a native common reed (*Phragmites australis* subsp. *americanus*) and a non-native European biotype (*Phragmites australis* subsp. *australis*), which is considered to be highly invasive in North America. Similarly, reed canary grass, *Phalaris arundinacea*, is an invasive species in Europe. These indigenous grass species are characterized by high biomass yields that can provide large amounts of bioenergy [10]. *Phragmites australis*is considered a serious threat to the biodiversity in naturally occurring wetlands [11, 12] but, at

the same time, it provides numerous ecosystem services as well. The small, patchy or mixed reed beds are a more suitable habitat for many species than extensive, dense reed beds [13]. They serve as an excellent sink for carbon sequestration and for the absorption of point-source pollution [14] as they absorb various heavy metals from the waterbeds of the wetlands [15]. Reed canary grass (*Arundo donax*) is considered as one of the most important energy crops and is extensively utilized in production systems because of its biomass quality [16]. Over the past 10 years, reed canary grass breeding has been carried out in Sweden and Finland for various industrial purposes [17]. The European Giant Reed (*Arundo donax* L.) Network, established in January 1997, aims to generate data on the viability of introducing this species into European Union policy agriculture for energy and pulp production. Reeds, in general are found to be an important component in the ecology and maintenance of wetland integrity by providing numerous ecosystem services. They possess valuable attributes, such as an extensive root system that maintains the adhesion of substrates and thereby minimizing soil erosion. They also have the ability to withstand environmental contamination and can assimilate heavy metals, tolerate varying degrees of salinity, acidity, among others [18]. Although the *Phragmites australis* reed beds appear to be a monoculture, the reed co-exists with other plant species providing a good habitat for numerous animals, birds and insect species [11]. They are a potential renewable resource because of the production of raw materials and biomass for fuel energy. This reed biomass can be used as an energy source in various ways such as combustion, biogas production, biofuel production [19, 20] and are hence called a "second generation" biofuel [21]. They are also used in phytoremediation in which they are good soil conditioners in agriculture [22] and the summer-harvested reeds are rich in various nutrients and are ideal to use as good fertilizers [23]. They are effectively used in waste water treatment as well as in the removal of accumulated toxic heavy metals [24]. In Latvia, common reed and peat utilization are the main sources of biomass energy production [25].

Reed bamboos: a case study of the endemic reeds (*Ochlandra* Thw.) of the Western Ghats, India

Reed bamboos, belonging to family Poaceae and subfamily Bambusoideae, are one of the most successful and diverse group of monocots which, along with other bamboos, are often known as 'poor man's timber' and the 'green gold of India' [26, 27]. Worldwide, there are 1400 species of bamboo belonging to 115 genera [28]. In India, 130 bamboo species under 18 genera are distributed in the Western Ghats, North Eastern India, Andaman-Nicobar Islands, the second largest reserve of bamboo resources in the world [26, 29]. The Western Ghats has 22 species under seven genera, which constitutes a major component of bamboo diversity with a high degree of endemism [29, 30] and is considered to be a microspot for endemic bamboos, including reed bamboo genus *Ochlandra* [31-34]. Members of this genus, the reed bamboos, with thin walled and thickly clumped culms, are the preferred raw material for traditional cottage industries as well as modern paper industries. Even though they have been heavily exploited by the paper and pulp industries over the years, resulting in the severe depletion of the resources base, no stringent scientific management practices have been implemented. This review compiles the available information on the biology, ecology, socio-economics and ecosystem services of this genus and identifies gaps in research so as to address the conservation and sustainable management of the endemic reed bamboo resources.

The taxonomy, ecology and biology of the endemic reeds (*Ochlandra* Thw.)

Taxonomy

The genus *Ochlandra* Thw. was first mentioned in Van Rheedes' Hortus Malabaricus (1685) [35] and was first described scientifically by Thwaites (1864) [36]. At first it was treated as '*Beesha*' [37] and,

based on its morphological character, was described as having seven species and one variety [32]. Various taxonomic revisions have been made subsequently [26, 30, 38-42]. For example, *O. ridleyi,* found reported from Malaysia has been transferred [43] to *Schizostachyum* [39]. As per the latest revision, the genus comprises ten species in two groups which are distributed in the Western Ghats of India, except for *O. stridula,* which is confined to Sri Lanka. Their taxonomic identification mainly relies on vegetative characters, which lead to taxonomic complexities. Morphological characteristics, which are employed in classification, are similar among some species. For example, *O. scriptoria,* found in the Western Ghats, exhibits a morphological similarity to *O. stridula* of Sri Lanka [29]. Since most of the vegetative characters are phenotypically variable, the anatomy of the vascular bundle is used as a diagnostic characteristic for taxonomic identification [44]. Morphological characteristics often fail to define species boundaries in the genus, and hence a precise molecular technique, such as DNA barcoding, has been envisaged as a necessary supplementary tool for ensuring the taxonomic identity of species within the genus.

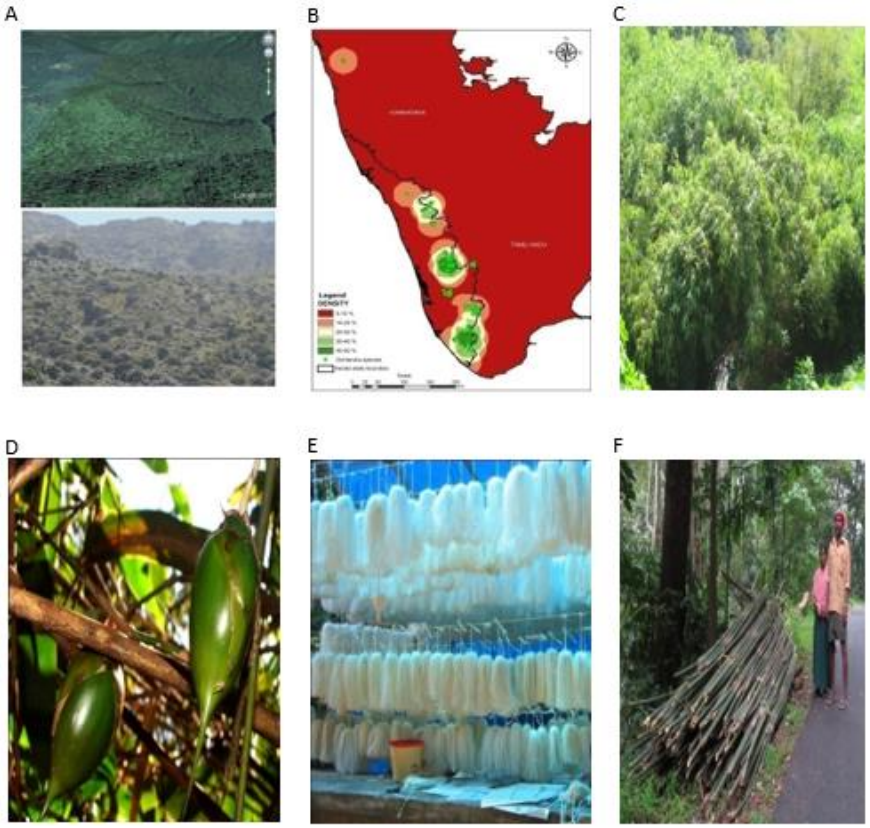

Fig. 1 (A) Occurrence of *Ochlandra* species as reed brakes (above), an arial view of reed brakes from Shendurney Wild Life Sanctuary in the Western Ghats (below), (B) Map showing the distribution of genus *Ochlandra* in the Western Ghats, (C) Habit of *Ochlandra scriptoria,* (D) *Ochlandra* fruit (*O. travancorica*), (E) *O. scriptoria* as 'odappuvu' in religious rituals of Northern Kerala and (F) Livelihood potential of reed bamboos.

Ecology and distribution

The genus *Ochlandra* is one of the ten members of Melocanninae, a monophyletic subtribe sister to all other paleotropical woody bamboos [45]. The members of this subtribe are mostly distributed across northeast India, Thailand, Madagascar and the Philippines, except for the genus *Ochlandra,* which is restricted to the Western Ghats of India and to Sri Lanka. Genus *Ochlandra* is confined to the tropical deciduous and evergreen forests of the Western Ghats as large reed brakes (Fig. 1A) (Table 1), which extend along the stream sides (Fig. 1B) [46]. Most of the species prefer moist soil and are normally regenerated by seeds or through rhizomes. They require an annual rainfall of more than 1500 mm [47]. *Ochlandra* reed brakes are mainly impenetrable thickets, 3 m to 5 m high and are naturally distributed among evergreen forests. They are mainly restricted to the moist areas of forest understory along slopes at an elevation of 200 m to 1000 m and are found especially along the stream sides of the Western Ghats [30, 32, 46].

Morphology and anatomy

Ochlandra, shrubby reed bamboos, attain a maximum height of 10 m (Fig. 1C) and their identification is mainly based on vegetative characteristics and, if available, on floral features. The taxonomic keys used for their identification are summarized in Table 2. The morphology of fruit is a dependable characteristic for taxonomic identification [48]. *Ochlandra* fruit, bacca, possess a thick fleshy pericarp which is usually seen separated from the seed coat (Fig. 1D). *O. ebracteata* has the largest leaf blade among the reed bamboos and occupies sixth position among the world bamboos. The large and leathery leaves help to establish a vigorous growth pattern in the evergreen forests of the Western Ghats [49]. The genus *Ochlandra* possesses prominent sympodial rhizome with a short, thick and curved branching pattern with longer internodes and solitary lateral buds [30]. The anatomy of lignin fibers has also been reported in *O. ebracteata, O. travancorica* and *O. scriptoria* [44, 50]. The anatomical features of other species within the genus are still undocumented and further studies are required to understand the cell transitional changes of the *Ochlandra* species.

Flowering pattern

Bamboos have characteristic flowering and fruiting cycles, ranging from a few years to 120 years. On the basis of flowering cycles, they are classified as annually (*O. scriptoria*) as well as sporadically (*O. travancorica*) flowering bamboos. *O. travancorica* and *O. wightii* are monocarpic in nature and regenerate naturally through seeds [51]. Some species (*O. wightii, O. scriptoria, O. travancorica, O. setigera*) exhibit both gregarious and sporadic flowering behavior [52-53]. *O. scriptoria* was thought to flower annually, without the subsequent death of the clumps [32], but recent reports have found that this species flowers in 20 - 21 years rather than annually [54]. The flowering of *O. travancorica, O. soderstromiana* and *O. spirostylis* was reported during 1997-1998 and the regeneration status of those species was investigated in 2007 when it was found that the natural regeneration of *O. travancorica* was profuse, whereas *O. soderstromiana* showed poor regeneration [55]. It is thought that anthropogenic activities had a greater influence on their regeneration, and both *ex situ* as well as *in situ* methods have been recommended for their conservation.

Table1. Natural distribution zones of *Ochlandra* species in the Western Ghats of India including their type locations [29].

Species	Type location and distributions
O. travancorica (Bedd.) Benth	India, Kerala, Travancore Hills, Thiruvananthapuram Dist. Agasthyamalai, Bonacaud, Nedumangad, Kottoor Reserve Forests; Kollam Dist. Shendurney Wildlife Sanctuary, Kulathupuzha; Pathanamthitta Dist. Plapilly, Goodrickal; Idukki Dist. Adimali, Vallakkadavu, Pambanar, Kallar; Ernakulam Dist. Pooyamkutty, Edamalayar; Kottayam Dist. Mundakkayam; Malappuram Dist. Nilambur; Thrissur Dist. Kollethirumudi; Palakkad Dist. Silent Valley
O. setigera Gamble	India, Tamil Nadu, Gudalur Dist. Nilgiris; Kerala, Malappuram Dist. Nilambur.
O. ebracteata Raizada & Chatterjee	India, Kerala, Trivandrum Dist. Paruthipally, Kottoor Reserve, Achenkoil; Kollam Dist. Thenmala, Ambanad; Thrissur Dist. Palapilly
O. wightii (Munro) C.E.C. Fisch	India, Tamil Nadu, Courtallam-Tennavelly, Kanyakumari Dist. Keerippara; Kerala, Thiruvananthapuram Dist. Palode, Nanniyode, Bonaccord, Nedumangad; Kollam Dist. Kallar
O. beddomeii Gamble	India, West slopes of Nilgiris-Wayanad; Kerala, Wayanad Dist. Thariyode
O. kadambaranii M. Kumar, Unnikrishnan & Remesh	India, Kerala, Kollam Dist. Nilamel, Pandimotta
O. scriptoria (Dennst.) C.E.C. Fisch.	India, Kerala, Ernakulam Dist. Peruvannamuzhi; Kannur Dist. Iritti; Kollam Dist. Kallada; Kottayam Dist. Mundakkayam, Erattupetta, Manimala; Malappuram Dist. Nilambur; Pathnamthitta Dist. Kattoor; Thrissur Dist. Vazhachal; Wayanad Dist. Chandhanathode
O. keralensis M. Kumar, Remesh & Stephen	India, Kerala, Pathanamthitta Dist. Pachakkanam
O. spirostylis M. Kumar, Seetha *et al.* Stephen	India, Kerala, Idukki Dist. Adimali, Chattuparakkudy
O. talboti Brandis	India, North Canara, Gursoppa falls; Karnataka, Kodagu Dist. Vir Rajpetta, Makutta

Table 2. The morphological (vegetative and floral) keys used for the taxonomic species identification of the genus *Ochlandra* [21 & 83].

Sl No	Characters	Species
1a	Leaves broad, 8-10 cm across, spikelet ovate-oblong, lodicules broad, 3-4, fruit subglobose to ovate-oblong	2
1b	Leaves narrow, 1.5-3.5 cm across, spikelets ovate-lanceolate, lodicules narrow, 6-7, fruit oblong- lanceolate	7
2a	Internodes rough, ventral side of the leaf rough, stamens around 40	*O. kadambaranii*
2b	Internodes smooth, ventral side of the leaf smooth, stamens 55-130	3
3a	Ligule conspicuous	4
3b	Ligule inconspicuous	5
4a	Ligule stiff, short, lacerate, 0.3-0.5 cm long	*O. ebracteata*
4b	Ligule membranous, long, fimbriate, 1.5-2.5 cm long	*O. wightii*
5a	Auricle conspicuous; leaf sheath hirsute	*O. keralensis*
5b	Auricle inconspicuous; leaf sheath smooth	6
6a	Style coiled or having a bend	*O. spirostylis*
6b	Style straight	*O. travancorica*
7a	Branches few, unequal	8
7b	Branches numerous, subequal	*O. talboti*
8a	Sheath tip thin; spikelets glabrous, inner sides of the blade glabrous	9
8b	Culm sheath tip thick; spikelets hirsute, inner side of the blade hirsute	*O. beddomei*
9a	Sheath papery, persistent, blade needle like	*O. setigera*
9b	Sheath coriaceous, deciduous, blade narrow	*O. scriptoria*

Pollination biology

Generally, grasses are considered anemophilous in nature due to their peculiar floral characteristics. The presence of dichogamous spikelets increases the pollination success in *Ochlandra* species [56], while the maturation of male and female stages at different time intervals was found to be a constraint in self-pollination. Cross-pollination was also observed in *O. travancorica* where pollen viability was found to be higher [57]. Reproductive biology studies showed a long gap of 48-72 hours for the transition of female stages into male stages in *O. scriptoria* [51] and *O. wightii* [58]. Larger bees often visit spikelets of *O. travancorica*, *O. ebracteata* and *O. scriptoria* and their destructive foraging causes heavy losses of pollen in these species [59]. At present, our knowledge on the pollination mechanism of *Ochlandra* species is very limited and more studies are necessary to better understand the possible gene flow and genetic drift among fragmented subpopulations.

Seed and seedling characteristics

Ochlandra seeds are recalcitrant in nature and lose their viability rapidly. The biochemical analysis on seed characteristics revealed a higher dry weight and circumference in *O. travancorica* than in *O. soderstromiana* and *O. spirostylis* [54]. Seedling attributes such as moisture content, germination, and seed viability have been reported in *O. ebracteata, O. scriptoria, O. travancorica, O. spirostylis* and *O. travancorica* var. *hirusta.* Higher moisture content has been found in *O. scriptoria* whereas *O. ebracteata* has a lower moisture content due to the higher intermast period of 7 years [60]. The seedling behavior of *O. travancorica* [52] and *O. wightii* [57] has also been reported. The structure and development of fruit and their systematic significance have been evaluated in *O. stridula* [61], a species from Sri Lanka and in *O. travancorica* (62). The seed biology of *O. travancorica, O. travancorica* var. *hirsuta* and *O. ebracteata* has also been reported [49]. Absolutely no information is available on the embryological studies of the genus *Ochlandra* and hence more research focusing on this aspect is required.

Ecological benefits of reed bamboos

Carbon sequestration potential

Although bamboos are grasses, they possess the remarkable ability to sequester carbon through photosynthesis and to lock carbon in the fibrous root system which is an important aspect of the forest ecosystem and the carbon sink [63-64]. Through their inherent ability to take up large amounts of CO_2 and convert it into oxygen, reed bamboo forests can help regulate CO_2 emissions that contribute to global warming. The CO_2 absorbed by the reed bamboos does not release back into the ecosystem as it is retained by the plant, and after harvesting, the culms and leaves are used for various value added products in industries. Thus, the reed bamboos serve as a carbon sink and the resulting environmental benefits are immense. Bamboo thus serves as an important niche for carbon conversion and locking [65] and hence the broad spectrum of bamboo products and services should be regarded as an important contribution to mitigating climate change.

Soil and water management potential

Reed colonization exerts a significant physical, chemical and biological impact on the soil. The biological activity of the fibrous root system of *Ochlandra* species with the micro organisms in the top layers of soil strata result in the formation of water stable macroaggregates. Thus the pure reed patches of *Ochlandra* species has been considered a stable vegetation climax capable of improving the physical properties of the soil and thereby stabilizing slopes and preventing land degradation [66]. Most of the *Ochlandra* species are riparian in origin as the river banks provide diffuse sunlight and moist fertile soil for healthy reed growth. *O. spirostylis* acts as a potential species in river bank stabilization [54].

Ochlandra species resist uprooting in winds and form population climaxes. Reed bamboos possess a large mass of foliage, culms and dry stalks which add large quantity of organic matter to the soil and help in the refinement of soil fertility, both physical and chemical aspects, through nutrient cycling. The soil in reed growing areas is rich in carbon content and replenishing nutrient characteristics by growing reeds has been suggested to improve the soil fertility in degraded soil [67-69].

Leaf litter plays a significant role in determining the structure and function of the forest ecosystem by acting as an energy source and a nutrient reservoir for heterotrophic organisms. A wide range of faunal populations have been observed in the reed growing soil which have a significant role in litter decomposition and soil enrichment. The water holding capacity of reed growing soil was also found to be higher when compared to non-reed areas due to the presence of the fibrous root system. Quality and quantity of water are two essential characteristics for the effective management of watersheds. Reed bamboos form an umbrella-like canopy in the evergreen forest areas. Since the vegetation is riparian in nature, it forms a kind of wall that checks the loss of flow in rivers [47]. *Ochlandra* species has thus been reported as a priority bamboo species to be conserved for the effective soil management of the Western Ghats [70].

Reeds as a keystone species

Reed bamboos function as a keystone species in evergreen forests, influencing the survival of many associated species and their ecological niches. It forms an important food source for the survival of gaur, *Bos gaurus* and *Daubentonia madagascariensis* which feed extensively on *Ochlandra* species [71]. *Ochlandra* species provides food and shelter for several forest fauna [72]. The fruiting of *O. wightii* supports the population of an endemic rodent *Platacanthomys lasyrus* [68]. The butterfly larvae of *Parantirrhoea marshalli* inhabit the leaves of *Ochlandra travancorica* [73]. Wild pigs feed on the fruit of *O. ebracteata* and the dried fruit is used as cattle feed [74]. The major *Ochlandra* growing areas are reported as elephant corridors [75] and bamboo culms are one of their favorite food delicacies. The arbuscular mycorrhizal fungi have a strong association with the fibrous root system of *Ochlandra* species [76]. Similarly, the faunal population of the reed growing area harbors diverse arthropods and annelids [77]. Reed bamboos also have a close association with the anurans (*Raorchestes ochlandrae*) of the Western Ghats which inhabits the hollow internodal regions of *O. setigera* [78]. *Raorchestes chalazodes*, a small frog, has been observed on the stalks of *O. travancorica* and *O. scriptoria* throughout its distribution zones [79]. As these frog species can only breed in reed bamboos, the unscientific over-harvesting of reed bamboos may destroy its breeding habitats and have a negative impact on the long term survival of anuran populations in the Western Ghats.

Ecosystem services

Strategies that support the ecosystem

Ochlandra travancorica and *O. wightii* have developed many adaptive strategies which help their successful existence in the wet terrains of the Western Ghats. These strategies are: the fibrous root system, vigorous growth, the production of baccate caryopses, adaptability to riparian life, absence of fruit dormancy and mycorrhizal associations. Healthy clumps of reed bamboos form an umbrella-like canopy which resists uprooting in winds and assists in the formation of population climaxes [80].

Socio-economics and livelihood potential of reed-based industry

Non-Timber Forest Produce (NTFPs) is considered eco-friendly, since harvesting causes less damage to the ecosystem than, for example, illegal logging. Reed bamboos are considered one of the most important NTFPs because of the subsistence and livelihood support they provide for the economically

weaker strata of society. In India, bamboo handicraft industries are widespread in the southern states, but this traditional sector is seeing a gradual decline in reed availability due to over-exploitation. The deforestation of reed areas for agriculture, multi-purpose river valley projects and permanent settlements add to the decline of reed resources and this affects the stability of the cottage industries [81]. *Ochlandra* species in particular plays a significant role for the livelihood of rural communities by providing source materials for construction, fencing, and handicraft industries, fodder for cattle and byproducts for medicinal purposes. The traditional tribal community, the Kadar of the Western Ghats, utilizes reed bamboos extensively for their livelihood as part of their culture [68, 82] (Table 3). *Ochlandra* species are also associated with some religious rituals during which immature culms of *O. scriptoria* are collected, crushed and made into a flower like product called *'odappuvu'* in northern Kerala (Fig. 1E) [83].

Bamboo has multiple uses and plays a crucial role in culture, art, industry and construction [84]. It is planted for hedges and used for landscaping [85]. In Kerala, bamboo cottage industries mainly use *Ochlandra* spp. (reed bamboos), particularly *O. travancorica* because of its high lignin and fibre content. For the last few years, the utilization of reeds has moved from cottage to commercial industry for paper and pulp production. About three million people in Kerala depend on the reed industry for their livelihood and about 3,500 local people are engaged in reed extraction and its transport from the forest (Fig. 1F). Kerala State Bamboo Corporation Limited (KSBC), an agency promoting reed based industry in Kerala State, was established in 1971 to regulate the pattern of reed extraction through the collection and distribution of reeds as well as the trading and marketing of the finished products [33, 86]. Some recommendations have been put forward to improve the functioning of institutions, as well as of the industries, in order to promote and manage the sustainable use of reed resources [87]. However, greater efforts should be directed towards improving reed production through appropriate technological interventions. Furthermore, existing policies for the sustainable use of resources need to be updated if the livelihood potential of reeds is to be sustained.

Population biology, conservation genetics and sustainable management

Population biology and conservation genetics

Information on the existing level of population genetic diversity is another prerequisite for meaningful future conservation strategies. One early study analyzed the genetic diversity of three *O. travancorica* populations in the Western Ghats and reported a higher level of variation within the populations. It also suggested an urgent need to assess the genetic diversity of other populations in the Western Ghats [88]. The assessment of the genetic diversity pattern of *Ochlandra stridula* Moon ex Thwaites of Sri Lanka has been reported using RAPD [89]. The population genetic diversity status of *Ochlandra* species in the Western Ghats is still undocumented and hence more studies need to be undertaken. Molecular marker technologies can be utilized for estimating the levels of genetic diversity among natural seedling populations for the future management of the available gene pool as well as for selecting clones for plantation purposes.

Conservation of the available natural resources can be accomplished mainly through *ex situ* as well as *in situ* approaches. Various factors such as weed infestation, seed predation by wild animals and other anthropogenic activities adversely affect the natural regeneration of *O. travancorica* and *O. wightii* in the Western Ghats [68]. *Ex situ* conservation relies on the selection of superior clumps from the naturally diverse populations and establishing them in artificial clonal banks, germplasm repositories for future plantation activities [34]. Similarly, *in situ* conservation should focus on genetically superior natural populations/ clones in their favored ecological niches. Both these conservation strategies can

be successfully executed through an understanding of available genetic variation at sub-population levels.

Table 3. Economic and industrial utilization of various *Ochlandra* species [30, 82 & 83].

Species	Uses
O. travancorica	Raw material for paper and pulp industry. Culms are used for making umbrella handles, fishing rods, handicrafts, 'bamboo ply' for hut walls, tool handles and agricultural implements Leaves are used for thatching
O. setigera	Culms are used for making handicraft items, tying firewood bundles Leaves are used as fodder
O. ebracteata	Ideal raw material for paper industry Culms are used for making baskets and mats Dried seed powder is used as cattle feed
O. wightii	Suitable for paper and pulp industry Culms are used for making huts Leaves are used as fodder
O. beddomeii	Ideal material for pulp industry Culms are used for making mats and baskets, and for construction purposes
O. scriptoria	Culms are used for making bamboo boards, flutes and rafts Young culms are used for making *'odappuvu'* in religious rituals

A survey conducted in 1968 estimated the exact growing stock of *Ochlandra* species in the Western Ghats as 10,000 $km^2$and the total reed growing area had been reduced to 9,400 km^2 by 1973 [90]. *Ochlandra* species are fast disappearing from their distribution zones due to over-exploitation as well as anthropogenic activities that affect their regeneration [91]. Fragmentation of the population leads to secondary succession or the complete disappearance of the existing reed brakes [92]. Although there are no reliable estimates of the total forest loss for the Western Ghats, several regional studies using satellite data revealed that only about 20% of the natural forest vegetation remains, and the remaining areas are in a highly fragmented state. It is estimated that 185 km^2 of the Kerala forests are dominated by the reed bamboos [93], but significant changes have occurred due to various factors such as fire, over-exploitation and anthropogenic activities. Extensive extraction of reed bamboos for traditional as well as commercial purposes is found to be the reason for the decline of reed population [94]. A basic strategy to conserve these resources is to gather sufficient information on species distribution by mapping the population. Several attempts have been made to map the resources throughout the Western Ghats with the aid of Geographic Information System (GIS) tools [95-101]. GIS mapping can

provide the information on species distribution in order to develop strategies for the sustainable utilization of the resources.

Silviculture and management of the genus Ochlandra

The gregarious flowering of *Ochlandra* species is found to be a major constraint for propagation from seeds. The unpredictable flowering and the consequent death of the clump along with short seed viability are the major hurdles for raising large scale plantations. Silvicultural practices have been reported in *Ochlandra* species (*O. ebracteata, O. scriptoria, O. travancorica*) [102] in which rhizomes have been separated from the culms during the onset of the monsoon, treated with growth regulators and planted horizontally in nursery beds. Several other vegetative means of propagation, such as offset reduction method, were also developed for propagating *Ochlandra* species in which plantlets are produced vegetatively using offsets derived from the parent rhizome [98]. Seedlings and rooted culm cuttings were best suited for field planting as evidenced by the high survival percentage and maximum culm production in *O. travancorica, O. beddomeii* and *O. scriptoria* [66, 103]. During the field trials, *Ochlandra* species always preferred wider spacing than other bamboos [104]. Vegetative propagation methods have also been standardized for planting stock production in *Ochlandra* species [105] where the main limitations reported are the unavailability of plant material and the difficulty in handling the large propagules. Micropropagation through tissue culture is an alternative method that can overcome these difficulties, but very few reports are available. *In vitro* flowers and plantlets were successfully produced in *O. travancorica* using hormonal supplements [106]. Micropropagation through callus induction from isolated embryos in *O. travancorica* and *O. travancorica* var. *hirsuta* [107] and nodal segments in *O. wightii* has been reported [108]. Further studies need to be undertaken to augment the large scale production of *Ochlandra* species using micropropagation depending on the demand and availability of the species.

Management of the reed bamboos

The regeneration of *Ochlandra* species is adversely affected throughout the Western Ghats due to the lack of scientific expertise and management practices followed during extraction. In order to overcome this problem, an expert committee was constituted by the Government of Kerala State, India in 1986, and certain strategies were recommended for the effective management of the existing reed resources. The strategies include scientific extraction depending on annual increment, protection from fire and grazing, periodic assessment of growing stock and strict adherence to the felling rules [27]. The need for adopting a scientific approach to increase the productivity of reed resources as well as to minimize the wastage during reed harvesting has also been emphasized [70]. For the effective management of reed resources, three prototypes of reed cutting tools have been developed to avoid the excessive wastage of culm material in the field during their extraction [109] and also post harvest technology has been developed for the outdoor storage of reeds to protect them from fungal deterioration [110]. For the sustainable management of reed resources, the Government of Kerala has proposed a closure period (June to September) for reed extraction in order to facilitate the regeneration of new sprouts and to reduce the excess wastage of raw material. In spite of all these regulations, the reed bamboos are under tremendous extraction pressure. If the extraction and management of the resources is to be sustainable, an immediate scientific intervention is required, which will support the effective regeneration and future survival of this endemic genus.

Implications for conservation

Ochlandra (reed bamboos) species are endemic to the Western Ghats of India as well as to Sri Lanka. They are one of the most highly exploited groups with fragmented populations throughout their distribution zones. The sustainable management of reed resources generates valuable ecological benefits, ecosystem services, biodiversity conservation and also provides raw material for the paper and pulp industry. Moreover, its diversity loss means the loss of a properly functioning ecosystem as well as the ecosystem services it provides. Hence, it is crucial to address the systematic conservation of *Ochlandra* species to ensure the viability and long-term persistence of populations and their biodiversity *in situ*. Proper conservation and the management of naturally occurring undisturbed areas should ensure that their natural values are retained without any anthropogenic pressures. The unpredictable flowering behavior, along with unscientific management practices during extraction, has resulted in the fragmentation of the natural reed populations and the decline of the resource. Hence proper scientific culm extraction and ideal propagation methods need to be practiced in order to replenish the existing fragmented reed bamboo resources. An inventory mapping the resources and cataloguing *Ochlandra* species is equally important for formulating conservation strategies. The depleting reed resources necessitate an urgent need for effective conservation and scientific management to ensure viability and the long-term persistence of these precious endemic natural resources in the Western Ghats.

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