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Assessing Ecological Sustainability of Non-Timber Forest Produce Extraction: The Indian Scenario

Ghazala Shahabuddin and Soumya Prasad

Non-timber forest products (NTFP) are extensively extracted from Indian forests, and their role in rural and forest economies is immense. However, the long-term ecological sustainability of NTFP extraction with respect to resource populations, dependent animal species and ecosystem functioning has remained largely unexamined. In this article NTFP research undertaken in India is reviewed in an attempt to understand issues related to ecological sustainability. There is a glaring scarcity of systematic research on ecological aspects of NTFP extraction in India. From the few available studies, it appears that species differ in their responses to harvest depending on the plant part extracted, natural history attributes and harvesting techniques. However, regeneration and population densities of some NTFP species are reported to be adversely affected by extraction. Such adverse effects, though, cannot be attributed to NTFP harvests alone, but rather to a combination of harvests, damaging harvesting practices and accompanying anthropogenic disturbances such as fire, grazing and fuel wood collection. There is little information on the long-term indirect effects of NTFP extraction on dependent animal species. The available literature also indicates a disturbing trend of ecosystem simplification due to intensive forest use, including extraction of NTFP, which may gradually lead to the weeding out of vulnerable plant species from Indian forests. Much more research is required before it can be clearly understood to what extent and in what ways livelihoods based on NTFP can be compatible with biodiversity conservation.

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Introduction

In the past, policy makers, forest economists and foresters have viewed forests primarily as a source of national revenue with timber as the dominant product (Tewari 1994). However, in an era of fast-declining old-growth forests, great significance is attached nowadays to forest products besides timber, that is, non-timber forest products (NTFP). Such forest products range from exudates (gums, resins and latex) to canes, fruits, flowers, seeds, seed derivatives, entire plants, leaves, root or stem bark, fungi, meat and by-products from game animals, animals for the pet trade, micro-organisms, and insects (Panayotou and Ashton 1992; Tewari 1994). Non-timber forest products differ from timber in terms of the greater variety of products and of species, the shorter frequency of harvest cycles and the typically smaller yields per unit area. However, as opposed to timber, rarely are entire plants harvested during NTFP extraction. Additionally, unlike timber that brings profits to state treasuries, economic benefits provided by NTFP accrue largely at the local level (Lelé 1994; Panayotou and Ashton 1992).

It has been proposed that long-term economic benefits from sustainable NTFP extraction might be significant enough to prevent forests from being put to more destructive land uses such as logging, mining or ranching, and help lower rates of tropical deforestation (Panayotou and Ashton 1992). This concept had its birth in the struggle of the Brazilian rubber-tappers to save their forests from encroaching ranchers and loggers during the late 1980s, which led to over 3 million ha of forests being set aside as extractive reserves (Fearnside 1989; Nepstad and Schwartzman 1992; Schwartzman 1992). The potential role of NTFP in forest conservation was further supported by several studies that demonstrated that the long-term financial return from sustainable NTFP harvest could far outweigh the net economic benefits of timber production or conversion of the same area of land to agricultural fields (Chopra 1997; Malhotra et al. 1992; Nepstad et al. 1992; Peters et al. 1989; Pinedo-Vasquez et al. 1992). These developments fuelled much excitement in the conservation community about the prospects of establishing extractive reserves that could help maintain biodiversity while simultaneously providing sustainable economic returns to local people and governments. Several authors have tried to temper this enthusiasm for extractive use by pointing out that there are many limitations to hypothetical calculations of the income derived from an average hectare of tropical forest (Fearnside 1989; Pinedo-Vasquez et al. 1990; Sheil and Wunder 2002; Vasquez and Gentry 1989) and have questioned the wisdom of using such valuation studies as a basis for conservation policy (Sheil and Wunder 2002).

In India, too, the role of NTFP in rural and forest economies is immense. Economically significant NTFP have been recorded from over 3,000 plant species extracted from forests and associated ecosystems in India (Tewari 1994). In certain areas, NTFP have been reported to contribute up to 40 per cent of the household income (Chopra 1997). NTFP extraction is very widespread, both within and outside protected areas. Kothari et al. (1995), for example, reported that NTFP are known to be extracted from fourteen (36 per cent) of the thirty-nine national parks and 104 (56 per cent) of the 185 wildlife sanctuaries in India (although NTFP extraction is not permitted in national parks and is allowed only with special sanction inside sanctuaries; extraction is permitted in reserved and other categories of forests, however [Anon 1972, 1980]). In India the role of NTFP in forest conservation has gained additional impetus lately with increasing emphasis on participatory models of forest conservation, such as joint forest management and community-based conservation, in which NTFP extraction constitutes an attractive economic incentive for local people (for recent reviews, see Kothari et al. 1997; Ravindranath et al. 2000).

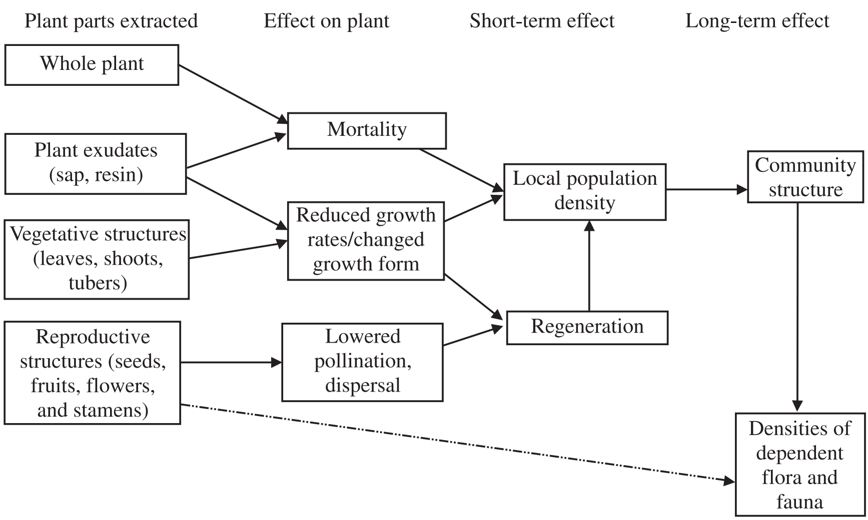
In the current climate of increasing support for extractivism as a tool for biodiversity conservation, the long-term ecological sustainability of such extractivism has unfortunately remained obscure and unstudied. However, recently there has been increasing concern globally about the impacts of NTFP extraction on populations subject to extraction, on resource users other than humans, as well as on ecosystem functioning (Bawa 1992; Bhatnagar 2002; Lambert 1998; Shankar et al. 1996, 1998; Ticktin 2004; Vasquez and Gentry 1989). In India, too, populations of commercially extracted species are reported to be declining in many parts of the country, and reports of adverse ecological impacts of NTFP harvest are becoming increasingly common (Mohan Ram, personal communication; Murali et al. 1996; Negi 2003; Shankar et al. 1998). Clearly, a rethinking of the linkages between forest produce extraction and ecological sustainability in India's forests is long overdue.

Sustainable resource use can be defined as the maintenance of an undiminished flow of benefits from the resource to its users over time (Lelé 1994). However, this deceptively simple definition is complicated by the fact that the various different benefits provided by any forest resource to its different users are generally not simultaneously maximised (ibid.). Homma (1992) proposed that if sustainability of NTFP extraction is to be achieved from the point of view of all resource users, then social, economic and political structures at local, regional and national levels need to be managed in such a way that NTFP extraction is lucrative over time, yields social improvement for its participants, and does not compromise ecological and agronomic equilibrium. In purely ecological terms, extraction can be considered sustainable if the harvest has no long-term deleterious effect on the reproduction and regeneration of populations being harvested in comparison to equivalent non-harvested natural populations, and if the harvest has no discernable adverse effect on other species in the community, or on ecosystem structure or functioning (Hall and Bawa 1993). We confine ourselves to discussing the ecological aspects of sustainability only, while recognising that forest management policy has to equally critically take into account political, economic and cultural contexts of forest use. In this article we review NTFP research done in India in an attempt to answer the following specific question: What are the possible impacts of NTFP extraction on target populations, on dependent animal species, and on ecosystem structure and function? Since the literature on hunting in India is still very limited, we confine ourselves to NTFP of plant origin.

IMPACTS OF NTFP EXTRACTION ON RESOURCE POPULATIONS

NTFP harvests may affect plant populations at two different levels: first, at the level of the individual, on vital rates such as growth and reproductive capacity; and, second, at the level of the population, which manifests in its demographic structure and long-term dynamics. The direct effects of intensive forest produce collection may include decline in productivity, density and/or regeneration of the targeted plant species, depending on the part of the plant that is utilised (Cunningham 2001; Peters 1994; see Figure 1 for a synopsis of the possible biological effects of NTFP harvest).

Figure 1
Possible Ecological Impacts of NTFP Extraction



An important approach to studying impacts of NTFP harvest on natural populations has been to examine whether there is sufficient regeneration of the resource population, particularly for tree species (Hall and Bawa 1993). The underlying rationale is that a continuously regenerating population will ensure that the resource is not depleted and there will be a continuous flow of benefits to people dependent on these resources over time. However, assigning cause and effect between resource use and observed regeneration is not straightforward for several reasons. First, it is difficult to locate control (unharvested) populations that differ from treatment (harvested) populations in every respect except for intensity of harvest. This is because anthropogenic factors such as grazing, fuel wood use, fire management, hunting, timber cutting and NTFP extraction are often correlated.

For example, in tropical dry forests in India, low-intensity fires that are lit for the purpose of making NTFP collection easier cause damage to seedlings and saplings of several tree species (Saha 2002). Lack of regeneration could also be due to other environmental stresses, such as herbivore damage, presence of invasive plant species, pathogens and resource deficiencies, whose effects may be enhanced under certain anthropogenic disturbances. Therefore, an observed lack of adequate regeneration of a target population could be due to one or a combination of these factors. Second, defining how much regeneration constitutes 'adequate' regeneration is not straightforward due to differences in vital rates and population parameters across species and across ecosystems.

The most commonly adopted approaches to overcome these practical difficulties in designing studies to assess impacts of NTFP harvest on target populations have been, first, to compare regeneration and girth-class distributions (proportion of individuals belonging to different size or age classes) of NTFP species at sites subject to different harvesting intensities. Typically, an inverse J-shaped curve that shows very high proportion of seedlings and saplings in relation to adult trees is considered to represent a healthy regenerating population. Sharply declining densities of individuals in successively larger size (or age) classes produces the inverse J-shaped girth-class distribution for a species. A second step in this approach is to compare girth-class distributions of harvested NTFP and non-NTFP species within a given forest area. However, in this case there may be the danger of glossing over important differences in natural history attributes of different species. Another approach is to use population modelling to assess impacts of various extraction pressures on population structure using empirically determined estimates of growth and reproductive rates. There have also been attempts to quantify genetic variability and reproductive fitness of populations subject to different intensities of harvest. Use of such measures offers insights into impacts of harvests on processes such as pollination, dispersal and gene flow within populations, and thus relate to long-term evolutionary consequences of harvest.

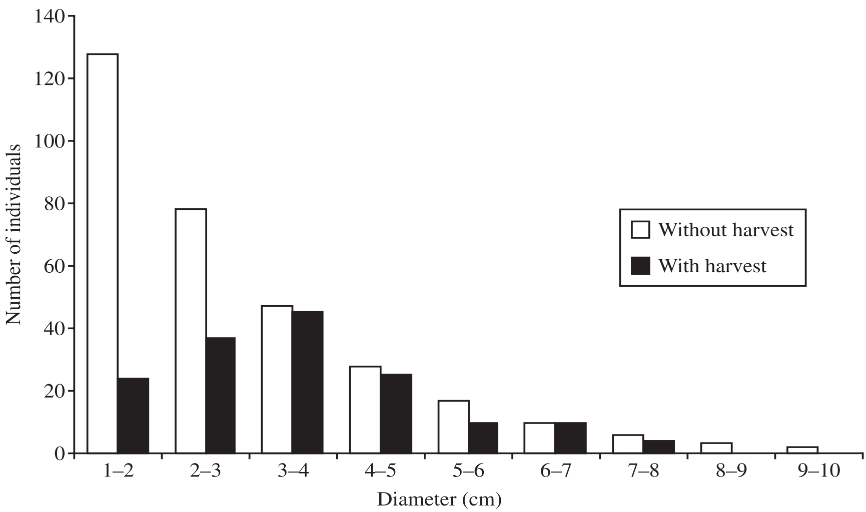
A large number of studies on the linkages between NTFP harvest and resource regeneration have emerged from long-term research being carried out at a single site in south India—the Biligiri Rangaswamy Temple (BRT) wildlife sanctuary (Murali et al. 1996; Shankar et al. 1998; Sinha 2000). Shorter-term studies have also been carried out at sites in central (Koliyal 1997; Pant 2003) and north-west (Prasad 2001) India. All these studies have focused partly or exclusively on *Phyllanthus emblica.* Some studies at BRT have also examined *Phyllanthus indofischeri, Strychnos potatorum, Terminalia bellerica* and *T. chebula* (Shaankar et al. 2001; Shankar et al. 1998; Sinha 2000), and Koliyal (1997) has studied *Madhuca latifolia* and *Buchanania lanzan* in central India. A recently concluded study, possibly the most comprehensive so far, has investigated the population status of *Garcinia gummi-gutta* in differently managed sites in wet evergreen forests of the Western Ghats (Rai 2003; see also Rai and Uhl in this issue). For all other NTFP such as *Shorea robusta*, *Diospyros melanoxylon, Boswellia serrata*, *Sterculia urens* and *Cordyceps sinensis,* literature that exists on demographic aspects of harvested populations is largely anecdotal in nature (see Table 1 for details of uses and parts extracted of these and other plant species mentioned in this article).

Table 1
Details of Parts Extracted and Uses of NTFP Plant Species

Species	*Part extracted*	*Uses*
Phyllanthus emblica (Euphorbiaceae)	Fruit, seed	Fruits in pickles; seed extracts in hair oil and medicines
Phyllanthus indofischeri (Euphorbiaceae)	Fruit, seed	Fruits in pickles; seed extracts in hair oil and medicines
Madhuca latifolia (Sapotaceae)	Flower, fruit	Flowers used for liquor; oil extracted from seeds; seed powder used as flour
Buchanania lanzan (Anacardiaceae)	Fruit	Fruits edible
Sida rhombifolia (Malvaceae)	Whole plant	Medicine
Sida cordifolia (Malvaceae)	Whole plant	Medicine
Asparagus racemosus (Liliaceae)	Bulbs (root)	Medicine
Dioscorea bulbifera (Dioscoreaceae)	Tubers (root)	Medicine
Hemidesmus indicus (Asclepiadaceae)	Rhizome (root)	Medicine
Decalepis hamiltonii (Asclepiadaceae)	Rhizome (root)	Medicine
Strychnos potatorum (Loganiaceae)	Fruit	Ripe fruit edible; used in medicine
Garcinia gummi-gutta (Guttiferae)	Fruit	Rind used as souring agent, and in medicine
Shorea robusta (Dipterocarpaceae)	Leaves, seed	Used for plates; seeds used for oil extraction
Diospyros melanoxylon (Ebenaceae)	Leaves, fruit	Leaves used in cigarette making; fruits edible
Boswellia serrata (Burseraceae)	Resin	For religious end products: frankincense and myrrh
Sterculia urens (Sterculiaceae)	Gum	For emulsifiers, adhesives, fixatives and laxatives
Cordyceps sinensis	Whole plant	Medicine
Chlorophytum tuberosum baker (Liliaceae)	Tuber (root)	Medicine, edible
Rauvolfia serpentina (Apocynaceae)	Tuber (root)	Medicine
Syzygium cumini (Myrtaceae)	Fruit	Edible
Artocarpus spp. (Moraceae)	Fruit	Edible

Many studies have found lowered regeneration of NTFP species at heavily harvested sites when compared to areas subject to lower harvesting pressures (Koliyal 1997; Murali et al. 1996; Pant 2003; Shaankar et al. 2001; Shankar et al. 1998; see Figure 2 for a hypothetical example). Some of these studies also report that regeneration of NTFP species was lower than that of non-NTFP species at heavily harvested sites (Murali et al. 1996; Shankar et al. 1998). The latter two studies also report overall low numbers of saplings in the smallest size class all over the BRT sanctuary, whether in high-intensity or low-intensity harvest sites, indicating extremely low rates of regeneration of not just NTFP, but several other tree species. For *Phyllanthus emblica,* the most widely studied species across the country, a number of studies have reported low seedling and sapling densities in intensively harvested areas compared to areas subject to lower extraction pressures (Koliyal 1997; Murali et al. 1996; Padmini et al. 2001; Prasad 2001; Shankar et al. 1998). In sharp contrast to these studies, Rai (2003) did not find any statistical difference in ratios of *G. gummi-gutta* seedling densities (<0.5 m in height, the smallest size class) to large trees (having greater than 20 cm girth at breast height [gbh]) between low-intensity and high-intensity harvest. There may, however, in fact be some differences in densities of saplings (>0.5 m height, but <40 cm gbh) between low-intensity and high-intensity harvesting sites when standardised with respect to tree density (see Figure 6 in Rai and Uhl in this issue).

Figure 2
Comparison of Hypothetical Girth Class Distributions of a Tree Species between Unharvested and High-intensity Harvested Sites



Note: The girth class distribution in the unharvested site shows a typical inverse J-shaped curve with high densities of individuals in the smallest seedling and sapling classes. Harvest of seeds often leads to low or absent new regeneration, but similar densities of adult trees. Such patterns have been observed for commercially important tree species in several sites in India.

Results from all of the above studies should be thought of as indicating broad trends rather than yielding conclusive results, given typically low sample sizes. The lack of control sites (where there has been no harvest), especially in comparable physiographic conditions, necessitates comparisons between many sites across a gradient of harvest histories and intensities. Use of distal and proximal sites as surrogates for low-intensity and high-intensity harvesting situations respectively (as in Murali et al. 1996; Shaankar et al. 2001; Shankar et al. 1998) is also problematic, given that foraging radii and routes may change from year to year. Additionally, some studies mentioned (for example, Rai 2003) intensive harvesting had begun only a few years before the data was collected. Impacts of harvesting on regeneration of the resource species may not be detected in such a short period. As indicated by results from a recent study across twenty-three sites in the Amazon (Peres et al. 2003), both history and intensity of harvests are major determinants of population structure of harvested species. Peres et al. (ibid.) found that juvenile recruitment was severely affected in populations subject to persistent harvests.

Another approach to assess impacts of harvests and other anthropogenic factors on resource populations is the use of matrix models used to model population dynamics (Boot and Gullison 1995). The validity of such models is critically dependent on accurate field estimation of plant growth rates and reproductive rates, which are likely to be very variable both spatially and temporally, necessitating extensive sampling in space and time (Freese 1997; Peters 1994). In India there have been few attempts to establish limits on harvests using such population modelling approaches. Shankar et al. (1996) have tried to define sustainable yield for *P. emblica* extraction at the BRT sanctuary, but their attempt was inadequate due to lack of sufficient data. And Murali and Srinivasulu (2000) modelled effects of different rates of extraction on plant densities of some medicinally important herb species at the BRT sanctuary: *Sida cordifolia*, *Sida rhombifolia, Dioscorea bulbifera, Asparagus racemosus, Decalepis hamiltonii* and *Hemidesmus indicus,* using an empirical approach (see Table 1 for uses of these plant species). In most cases, more than 25 per cent extraction was found to be detrimental to local plant populations. The most comprehensive work on these lines was carried out by Rai (2003) who quantified growth rates and reproductive capacity of *G. gummi-gutta* trees. For this population, even very high levels of harvest of seed (up to 90 per cent) were demonstrated not to affect the future structure of the resource population (ibid.). However, a sharp decline in tree populations was projected beyond 90 per cent seed harvest. As model parameters can vary substantially between years depending on climatic conditions and other ecological factors, model projections as in Rai (ibid.), and Murali and Srinivasulu (2000) should be treated as tentative. Further work, taking into account temporal and spatial variability, is required to substantiate findings such as these.

Genetic studies offer opportunities to examine long-term evolutionary implications of chronic harvesting on resource populations. The few genetic studies of NTFP species from India are largely suggestive and are constrained by being limited to a few loci. Shaanker et al. (2001) found no significant differences between populations of *Terminalia bellerica* and *T. chebula* for genetic diversity parameters across a disturbance gradient (control, moderate and high) at the BRT, but there were some appreciable differences between the disturbance levels as seen with principal component analyses (PCA) for both species. This suggests that extraction may have altered the genetic structure of these two plant populations. For *P. emblica,* Padmini et al. (2001) found that extraction of fruits may lead to loss of reproductive fitness and genetic differentiation of populations across disturbance gradients at two sites (BRT and Mudumalai wildlife sanctuary). While several seed and seedling features were significantly affected by disturbance at both sites, genetic diversity decreased with increasing disturbance only at one of the sites (Mudumalai). Populations close to human settlements tended to cluster together and were separated from those farther away within each site and on pooling samples (ibid.). This suggests that *P. emblica* populations are affected nearly similarly by anthropogenic pressures at these two sites.

Many studies have indicated that damaging harvesting methods affect resource populations equally or more than the actual removal of plant parts. Sinha (2000) found that fire had a larger effect on population growth rates than actual harvests for *Phyllanthus emblica* and *P. indofischeri* at the BRT. Traditional non-destructive methods are increasingly being replaced by less time-consuming and less labour-intensive methods in India, both due to increase in demand for NTFP and the open-access nature of forest land (see Rai 2003). Removal or damage of reproductive individuals may have the greatest impact on population growth in slow-growing tree species. Sinha and Bawa (2002) found that populations of *P. emblica* and *P. indofischeri* were more sensitive to destructive harvesting (for example, lopping of branches) than to fruit harvest per se. They found that such harvesting techniques reduced fruit production the following year for these species. Rai (2003) similarly found that population growth was more sensitive to adult tree mortality caused by lopping than to harvest of *G. gummi-gutta* fruit in wet evergreen forests of the Western Ghats. Koliyal (1997) and Pant (2003) have also reported destructive harvesting practices in deciduous forests of central India with branches, and sometimes whole trees, being cut down to obtain fruits.

Effects of extraction on local population densities of extracted plant species, particularly tree species, may be expected to manifest only in the long term. However, in several cases, adverse effects have already been observed on adult populations of plants. Shankar et al. (1998) found that NTFP species exhibited greater densities and basal areas in sites subjected to relatively lower extraction pressures compared to heavily extracted sites. Anecdotal information exists from other areas, though this needs to be substantiated by systematically collected long-term data. Several commercially important species are likely to become extinct in Sheopur forest division in Madhya Pradesh, including *Boswellia serrata*, *Sterculia urens* and *Phyllanthus emblica* (Bhattacharya and Hayat 2003). Several species of rhododendrons in Sikkim are thought to be under threat of extinction from over-exploitation for fuel wood and incense manufacture (Singh et al. 2003). Similarly, surveys of *Cordyceps sinensis* in Uttaranchal, a composite fungus larva organism formed by the parasitisation of a moth caterpillar by fungus, indicate that the population of this species in Uttaranchal is visibly declining even on an annual basis due to the pressure from human extraction (Negi 2003). Interviews with village groups managing central Indian forests in Gadchiroli, Maharashtra, indicate that there is a general perception of population decline in *Sterculia urens* due to over-exploitation of gum (Shahabuddin, personal observation). Rapidly declining densities of *Acacia catechu*, a species whose bark has been harvested intensively for *katha* manufacture during the last few decades, has been reported from the Aravalli hills of north-western India (Mohan Ram, personal communication). Availability of medicinal plants such as *Chlorophytum tuberosum* and *Rauwolfia* *serpentina* is also under serious threat in central Indian forests due to over-exploitation (Boaz, undated).

Impacts on Other Species

The removal of a given plant product from a forest may also adversely affect dependent animal populations, the effects of which could then reverberate through forest ecosystems as many of the affected species could be significant pollinators or fruit dispersers (see Terborgh 1998). With ever-increasing habitat loss and fragmentation, NTFP resources could currently be of critical importance to the survival of threatened populations of animals, particularly those sourced from keystone species (ibid.). The degree of specialisation of animal species with respect to specific plant products would determine, to a large extent, the degree of impact. In the long term, it is possible that large-scale export of nutrients from these forests in the form of various plant parts may be unsustainable, though these effects are rarely studied (Salafsky et al. 1992). Though it is well-recognised that humans share forest resources with a large number of other species, there have been few studies to date looking at sustainability of NTFP extraction from the point of view of other resource users (but see Bakuneeta et al. 1995; Chapman and Onderdonk 1998; Lambert 1998; Prasad 2001). Could extractive activities become unsustainable to these other resource users?

Extraction of forest produce might degrade the quality of the habitat of dependent species due to reduction in quantity of available food. Prasad (2001) investigated impacts of fruit harvest on the frugivore community of *P. emblica* at Rajaji National Park in north-west India. At Rajaji, *P. emblica* fruits were con-sumed by four mammals—langur (*Semnopithecus entellus)*, chital (*Axis axis),* barking deer (*Muntiacus muntjac)* and Indian gerbil (*Tatera indica)*. For these frugivores, extraction of fruits by people represented loss of a food resource (ibid.). Current knowledge of the ecology of certain frugivorous species suggests that loss of food resources due to NTFP extraction might limit wildlife populations. For example, Green and Minkowski (1977) observed that in the *shola* forests of the Western Ghats, harvesting of the scarce *Artocarpus* spp. fruits deprived the lion-tailed macaque (*Macaca silenus)* of one of its most important year-round foods. Kumar (1985), from a year-long study of the lion-tailed macaque, found that removal of selected products like fruits of *Artocarpus hirsuta*, *Syzygium cumini* and cane could drastically alter food resources of this species, even if done rarely.

In particular, extractive uses have the potential to limit food resources of animals like the brown palm civet (*Paradoxurus jerdoni),* which are heavily dependent on seasonal and spatially patchy resources such as fruits (Herrera 1982; van Schaik et al. 1993). Fruit resources constitute a large fraction of the diet of the brown palm civet (a mammal endemic to the Western Ghats) in all seasons (Mudappa 2001). For the thirty-four plant food items identified to species level in the diet of the brown palm civet by Mudappa (ibid.), we found that fourteen (29 per cent) had uses listed for fruit or seeds, twenty-three (68 per cent) had parts other than fruit or seed used by people and only eight (23 per cent) had no uses listed in the volumes of *Wealth of India* (Anon 1976). It remains to be examined whether such human uses have actually limited population sizes and distribution of the brown palm civet or other dependent animal species.

Rai (2003), however, has noted that there may not necessarily be competition between frugivores of *G. gummi-gutta* and fruit harvesters if fruits are picked off the ground after natural fall rather than directly harvested from trees. Most recorded frugivores are arboreal and likely to consume pulp from fruits on the tree itself while only the hard, uneaten rind, which is left on the ground, has market value. Nonetheless, while traditionally *G. gummi-gutta* was harvested by picking the rind off the ground, large-scale commercial extraction mostly involves collection of fruits from trees (Balachandra Hegde, personal communication).

Of special concern within protected areas in India is the association of illegal hunting with legitimate forest-based activities such as NTFP extraction (A.J.T. Johnsingh, personal communication; Madhusudan and Karanth 2000; Prasad 2001). It has often been argued that permitting NTFP extraction in protected areas might lead to such collateral damage, which could take a heavy toll on wildlife within these areas. Thus, in areas designated for wildlife protection, permitting NTFP harvests might have other far-reaching consequences, even for species that are not dependent on the resource directly, in ways that have yet to be understood.

Effects on Community Composition and Ecosystem Functioning

Declining densities and regeneration of extracted species can lead to substantial changes in structure of forest communities. Such changes might be reflected in a shift in the composition of plant communities as well as a lowering of diversity, biomass and net primary productivity of these ecosystems. A growing body of literature based on studies conducted in various parts of India indicates that intensive human use of forests is leading to a gradual change in forest ecosystems characterised by species impoverishment and, consequently, ecosystem simplification. Species exploited intensively for their parts, those vulnerable to fire, invasive species, grazing and repeated lopping, those dispersed exclusively by animals, or those germinating in specific micro-climatic and soil conditions, appear to be at risk and may be getting 'weeded' out from intensively exploited forests (Daniels et al. 1995; Ganeshaiah et al. 1998).

Though there are no studies that have focused exclusively on impacts of NTFP harvest on community composition or ecosystem function, extractive uses have been listed as one of the anthropogenic pressures that has brought about these changes (ibid.). As an example, it has been observed that deciduous forests are slowly being taken over by increasing density of scrub forest species at the BRT sanctuary (ibid.). Similarly, it has been documented that evergreen and deciduous species in wet evergreen forests of the Western Ghats are giving way to species that have features adapted to arid climates (Daniels et al. 1995). Ganeshaiah et al. (1998) and Pant (2003) found that long-term anthropogenic pressures had led to animal-dispersed species becoming less common, and wind-dispersed plant species increasing in density, resulting in a shift in phyto-sociological attributes of plant communities. In the *Shorea robusta*-dominated forests of south-western West Bengal, it is feared by many that intensive extraction of biomass over the last two centuries may have converted originally multi-species *Shorea*-dominated forests to almost mono-cultural stands (T.K. Mishra, personal communication; Palit 1999; Shahabuddin 2002). Throughout this region, regeneration of *Shorea robusta* is very low and is regarded as a serious problem today. Quantitative studies have shown that areas subject to lower levels of extractive pressures were more diverse in terms of tree species and had lower densities of *S. robusta* in proportion to other species (Das et al. 2000; Lal et al. 1993; Mishra and Banerjee 1997; Ramnarayan et al., undated). As mentioned earlier in this article, where overall poor rates of regeneration of several tree species have been recorded through extensive sampling at the landscape level at BRT (Murali et al. 1996; Shankar et al. 1998; see Figure 2). These observations portend a highly species-poor scenario in the future for regions subject to intensive harvests. Only long-term vegetation studies in intensively used forests can help quantify some of these changes thought to be underway in forest ecosystems on a large scale.

CONCLUSION

The current review indicates that there is scant, mostly anecdotal, information on the ecological sustainability of extraction of the hundreds of NTFP in India, obtained from various plants. Only a few species of trees have been studied quantitatively and over adequate spatial and temporal scales for discerning possible harvesting impacts; there are next to no studies on herbs and shrubs.

The available literature indicates that species and populations differ in their responses to harvesting, as would be expected. The degree to which plant populations are adversely affected by harvesting depends on natural history attributes of plant species, harvesting techniques adopted, the extent of extraction and the plant part used (see also Rai 2003; Ticktin 2004). However, it is also clear that several NTFP plant species in India may be subject to unsustainable use as indicated by lowering of adult population densities and reduced regeneration ability, even inside protected areas. In many cases, it is likely that forest use practices that typically accompany harvesting activities, such as grazing, fires and tree cutting, and accompanying micro-climatic and soil changes, may have as much or greater impact on regeneration of resource populations as does actual removal of plant parts. Certainly, taken together, harvesting of plant parts and accompanying forest use practices are having an overall detrimental effect on plant regeneration and densities of studied NTFP species in many sites. There is also evidence from the published literature that NTFP extraction and accompanying forest use practices may be leading to overall forest ecosystem simplification due to selective extinctions of plant species in the long term.

Recent ecological studies on frugivorous and other animal species indicate that NTFP extraction may represent a significant loss of food resource and changes in habitat structure for dependent animal species. A near absence of long-term quantitative studies makes it difficult to link population declines of dependent animal species, if any, with NTFP harvests. Nonetheless, from current knowledge of plant–animal linkages in tropical forest ecosystems, we infer that collection of plant parts is particularly likely to have an impact on specialist animal species.

The current review thus indicates that in the process of planning for forest use, we need to not only recognise potential impacts of NTFP extraction on target species, but also on other resource users of the same resource, as well as on ecosystem processes. A more rigorous information base on important NTFP species throughout the country needs to be built up before extractive uses or interventions can be planned in Indian forests, especially in areas designated for wildlife protection. Much more research is required before it can be clearly understood *to what extent* and *in what ways* livelihoods based on NTFP can be compatible with biodiversity conservation.

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