Netherlands Journal of Agricultural Science 45 (1997) 439-450

Extraction of non-timber forest products from tropical rain forests. Does diversity come at a price?

R.G.A. BOOT

Programa Manejo de Bosques de la Amazonia Boliviana, Casilla 107, Riberalta, Beni, Bolivia. (Fax: 591-852-3243; e-mail: promab@latinwide.com) / Department of Plant Ecology and Evolutionary Biology, Utrecht University, P.O. Box 80084, NL-3508 TB Utrecht, The Netherlands (fax: 31-30-2518366; e-mail: wimd@boev.biol.ruu.nl)

Received 4 August 1997; accepted 31 December 1997

Abstract

Tropical rain forests are rich in plant and animal species. The sustainable extraction of non-timber forest products has been advocated as a strategy to best conserve this diversity. However, the development and implementation of such exploitation systems, which aim to reconcile conservation and economic development, are still hampered by the lack of information on the biological sustainability of these systems, the impact of these exploitation systems on the biological diversity and the insufficient knowledge of the role of forest products in the house-hold economy of forest dependent people and hence their prospects for economic development.

Whether the exploitation of non-timber forest products from tropical rain forests is sustainable or not is still open to question, but data presently available on the biological, social and economic aspects of these extraction systems point at an interesting question: Does diversity come at a price? Namely, low density of conspecifics – and thus products – and hence low productivity for those involved in the collection of forest resources.

The paper will further discuss whether domestication of forest species provide an alternative for some of these species? Species are part of a complex ecosystem and their functioning is partly depended on the presence of other species in the system. What are the attributes of the species which have to be taken into account in order to make domestication of forest species successful?

Finally, the paper will return to the question: How to reconcile conservation and use of tropical rain forests? It will present a case for domesticating the forest instead of the species. Or in other words changing the forest composition without changing its structure and functioning, and maintaining acceptable levels of biodiversity.

Keywords: non-timber forest products, forest management, domestication, brazil nuts.

Introduction

The wealth of plant and animal species inhabiting the tropical rain forests of the world is well established. Tree inventories by Gentry (1988) and Ashton (1984) in

Amazonia and Southeast Asia, respectively, illustrate this astounding diversity. Both authors recorded up to three hundred tree species per hectare divided over just five to six hundred trees. Which means that almost every second tree on their single hectare plots belongs to a different species.

Indigenous and other forest-dependent people have made use of this biological diversity for millennia by extracting a wide range of products for subsistence or trade, such as: edible fruits, nuts, medicines, construction materials, latexes, resins and so on. For example, in the Upper Amazon region near Iquitos, Peru, Vasquez & Gentry (1989) found that inhabitants of the region consumed 139 different species of native fruits, with the majority of them harvested exclusively from local forests. Another example of the diversity of tropical forest trees used by forest-dwellers is provided by Boom (1985a,b). In a well-documented ethnobotanical study of the Chacobo tribe in northern Bolivia he found that this indigenous tribe have a use for 75 out of the 91 tree species found in one hectare of forest.

In recent years various authors have advocated the sustainable use of non-timber forest products (NTFP) from tropical rain forests as a strategy to best conserve the diversity of these forests (Allegretti, 1990; Anderson, 1990; De Beer & McDermott, 1989; Peters *et al.*, 1989). The basic assumptions which underlie this strategy are (i) the exploitation of NTFP is biologically sustainable and (ii) has no measurable impact on the structure and functioning of the forests from which they are harvested. A third assumption, implicitly made by some advocates, is that the extraction of NTFP provide an important source of income for forest-dependent people, and hence play a key role in the economic development of rural people living in regions covered with species-rich tropical rain forest.

But how true are these assumptions? Hall & Bawa (1993), for example, present some cases of biologically non-sustainable exploitation systems of NTFP, such as the rattan and copal gum extraction in many parts of Southeast Asia (Siebert & Belsky, 1985). Lamb (1991) also expressed his doubts about the effectiveness of traditional methods in preventing over-harvesting. Still others have expressed their doubts about the potential of NTFP to contribute to the economic development of forest-dependent people by writing that in practice extraction of these products very often only leads to a perpetuation of poverty among rural people.

Whether the exploitation of NTFP from tropical rain forests is sustainable from a biological, social and economical point of view is still open to question. The data presently available do not allow for general conclusions. However, the species-richness of tropical rain forests has consequences for the sustainable extraction of NTFP. High species diversity inevitably means low density of conspecifics, and hence a low availability of the products these species provide. This is likely to have consequences for the sustainability of exploitation systems both from a biological and socio-economic point of view. For example, commercial or high intensity extraction of low density populations may easily lead to over-harvesting and, as a result of that, the depletion of the resource. Secondly, low density of species and products will also have an impact on the productivity of forest product collectors. Low density in that sense may equal low productivity.

These observations, of course, are not inherent for NTFP. For example, extraction of NTFP from forests which are dominated by one or just a few species appear to be biologically sustainable and provide a substantial income for the people involved in the extraction (see Peters (1996) for some examples). However, in spite of the successfulness of these exploitation systems in species-poor ecosystems it is important to note that they do not help to conserve the species-richness of tropical forests and hence do not provide support for the thesis that conservation and economic development can be achieved through the sustainable exploitation of NTFP.

In this paper I will summarise some of the information presently available on the sustainability of NTFP exploitation from a biological and socio-economic point of view. The paper will focus on the commercial extraction of these products, because only commercial extraction of NTFP, in contrast to extraction for subsistence, has the potential to contribute to the economic development of forest dependent people. Secondly, I will discuss some management systems available to increase the density of the desired species in the forest ecosystem. Thirdly, the paper will address some ecological constraints associated with the latter and finally, the paper will return to the question: How to integrate conservation and economic development of tropical rain forests? The paper will present a case for domesticating the forest instead of the species. Or, in other words, changing the forest composition without changing its structure and functioning, and maintaining acceptable levels of biodiversity.

The sustainability of Non-timber forest product extraction

The ecological impact of NTFP extraction on both the species providing the resource and the ecosystem at large depend on the floristic composition of the forest, the nature and intensity of harvesting, and the particular species or type of resource under exploitation (Boot & Gulisson, 1995; Peters, 1996). Given that the initial impact of extraction is to a large extent determined by the latter, Peters (1996) categorised NTFP according to the specific type of plant tissue harvested, such as: reproductive propagules, plant exudates and vegetative structures.

The extraction of reproductive propagules, such as: fruits and seeds, does not affect the parent tree itself, neither the tree's reproduction in the years after. But collecting seeds may have consequences for the species' regeneration, and thus the future stock of mature trees. Harvesting of vegetative plant structures, such as the apical meristem – palm heart – of the asai palm (*Euterpe precatoria*), represents a contrasting form of resource exploitation. The individual plant dies after its apical shoot is removed, resulting in a lower number of mature individuals in the population and a reduced reproductive output in the future. Finally, the extraction of latexes or resins illustrates a third avenue of how exploitation influences the plant's functioning. Data from rubber plantations in Southeast Asia (Dijkman, 1951) suggest that rubber tapping negatively affects the tree's growth, its survival and its reproduction. The extent of this effect, however, strongly depends on the intensity and frequency with which these resources are extracted.

These examples illustrate the different effects extraction of NTFP can have on the individual plant. The plant's functioning can be unaffected, the plant can die or, more subtle, its growth, reproduction or probability to survive in the following years can be reduced as a result of exploitation. These different effects of extraction on the individual plant affect the size and structure of the population which ultimately determines the availability of the resource.

Extraction of non-timber forest resources thus differ in their effect on the individual and population supplying the resource. But, they have in common that their exploitation primarily affects the population from which the resource is extracted and probably to a far lesser extent the forest ecosystem in which the species or population thrives. This distinguishes them from timber resources. The felling of trees, the major component of the forest structure, changes the environmental conditions within the forest ecosystem, which in turn has important consequences for the number of individuals within a population affected by exploitation. The effects of NTFP exploitation are mostly restricted to the plants exploited. In contrast, timber extraction often affects all stages in the tree's life cycle either directly, through the removal of trees, or indirectly, through the change in environmental conditions within the forest ecosystem. In addition, timber extraction, through its change in forest structure, is also likely to affect the functioning and regeneration probabilities of other species in the system. This, in turn, may lead to changes in the relative abundance of species and/or the biological diversity of the ecosystem at large.

Although little data are available on the sustainability of NTFP exploitation and their effect on the structure and functioning of ecosystems, including their biological diversity, two aspects are probably of key importance: the intensity with which NTFP are harvested and the type of plant tissue harvested. The extraction of vegetative structures resulting in the death of the individual providing the resource are less likely to be sustainable than the extraction of reproductive structures or plant exudates. Secondly, the higher the intensity of extraction, the less likely it is that the NTFP are extracted in a sustainable way (see also Peters, 1996).

The sustainability of NTFP exploitation systems from a socio-economic point of view is more difficult to evaluate. A more narrow definition used for the purpose of this paper would be the daily income generated with this activity and the competitiveness of this activity with other sources of income.

A preliminary study on the costs and benefits of the exploitation of brazil nut by rural and urban-based seasonal migrants in northern Bolivia showed that most people only make a rather modest daily income with this activity (Edgardo Ribert, personal communication). Data on the economics of asai (*Euterpe precatoria*), jatata (*Geonoma deversa*), and , although nowadays at a rather small scale, rubber (*Hevea* spp.) extraction in northern Bolivia also suggest that, perhaps with the exception of asai, the daily income generated by the extraction of these products is rather low. These results confirm Browder's (1992) finding that rubber extractors in Amazonia typically earn a cash income barely sufficient to ensure household subsistence.

The little data presently available on the importance of NTFP for the household economy of forest-dependent people does not allow for broad generalisations, but one aspect related to this seems to be true for most NTFP extracted from species-rich ecosystems: the low productivity of the people involved in the extraction of the product (see also Browder (1992)). This low productivity raises questions with respect to the competitiveness of the activity in comparison with other activities, and its potential to contribute significantly to the economic development of rural people living in regions covered with species-rich tropical forests.

Both of the above mentioned observations: low productivity of NTFP collectors and the non-sustainability of commercial NTFP extraction systems, are related to a simple but often over-looked characteristic of species-rich tropical rain forests. High species diversity means low density of con-specifics. And low density often equals low productivity of the collector because labour time is expended in lengthy and frequently interrupted collection activities, which strongly reduces the efficiency of labour.

Increasing the availability of NTFP

Increasing the availability of NTFP per unit area would help to increase the productivity of those involved in the extraction of these products and may help to avoid over-harvesting of the NTFP exploited. Experiences with the collection of brazil nuts in northern Bolivia provide a good example of what can be done to increase the productivity of the collector by increasing the production of brazil nuts per unit area.

Any silvicultural treatment which increases the number of seeds produced per unit area, and especially of those areas close to roads and/or river sides will positively affect the productivity of brazil nut collectors, because more brazil nuts can be collected in less time or with less effort. In general this can be achieved by increasing the seed production of individual trees in a given stand or increasing the density of reproductive adults in the stand.

A three-year study on the fruit and seed production of a population of 42 brazil nut trees in northern Bolivia, near Riberalta, showed that fruit production of this tree species was positively correlated with the size of the tree crown and the tree's diameter (Lleigue, Goubitz and Nijkamp, unpublished results). It further showed that fruit production of the population studied remained more or less constant. The difference in fruit production between the first two years was only 3%, and between the last two years 6%, whereas the production of individual trees varied substantially from –1000 to + 300% between the three years. Another interesting finding was that although there was a positive correlation between tree diameter and fruit production, trees similar in diameter could easily differ a factor five to ten in their average fruit production in 1994, 1995 and 1996. A visual inventory of the environmental conditions known to affect fruit production suggested that some of this variation might be attributed to inherent or genetic differences. The same study also showed unambiguously that trees infested with climbers produce significantly less fruits than those free of climbers. The mechanism behind this finding is probably that climbers compete for light in the crown of adult brasil nut trees reducing the production of assimilates for the tree to invest in its offspring.

These findings have important implications for the exploitation of brazil nuts in natural stands. For example, the reduction in seed output by adult trees in the presence of climbers suggest a relatively simple silvicultural treatment: the cutting of climbers which will result in an increase in seed or fruit production of these trees in the years after. Second, large between-tree variation in fruit production suggest that enrichment activities should preferably use seeds from more productive individuals. However, with respect to this latter finding care should be taken not to reduce the genetic variation in plants used for these so-called enrichment activities to avoid inbreeding and reduced reproduction. Secondly, it is important to bear in mind that a high reproductive output does not necessarily mean a high growth rate or a high resistance to diseases. Planting seedlings of these valuable species in abandoned agricultural fields will result in high-density stands close to human settlements. Again, although only after a longer period of time, this will increase productivity of the brazil nut collectors.

Indigenous forest management systems

Some of the silvicultural practices which were suggested above to increase the production of brazil nuts per unit area are anything but new. For example, the average density of the brazil nut tree in northern Bolivia is less than five adult seed-producing trees per hectare. However in some areas the density of this tree can be as high as 15 per hectare. According to Balée (1987, 1989) this can be attributed to the influence of indigenous tribes in the past.

In general indigenous tribes are known to have modified their surrounding forests in two different ways: by clearing and burning small patches of forest and controlling or manipulating the succession which follows afterwards, or more gradually by altering the densities and distributions of useful species in otherwise undisturbed or structurally unchanged forests by selectively removing some species and planting or protecting useful ones (Padoch et al., 1985).

The Kayapo indigenous tribe of the Brazilian Amazon provide a good example of the first management practice: manipulating the succession which takes place in abandoned agricultural fields. The agricultural systems used by this tribe are usually mixed crop agroforestry systems with herbaceous and tree crops. The introduction and protection of useful plant species in these fields results in a forest rich in useful species which are still visited by this tribe many years after they 'abandoned' their fields (Padoch et al., 1985).

Indigenous forest management systems which change or manipulate the species composition of tropical forests without first clearing the stand are also known and documented. Some examples of this type of forest management are described by Peters (1996) in his overview of the ecology and management of NTFP. For example, in forests dominated by açai (*Euterpe oleracea*), common on floodplains in the Amazon estuary, useful species such as: cacao, cupuaçu, coconut and mango are frequently planted to increase the density of these valuable species in the forest. The growth of these species is sometimes even enhanced by placing dead leaves and inflorescences of the açai palm next to these transplants. Liberation thinning and girdling of large trees with no value is further used to stimulate the growth of desired species without severely damaging the residual stand.

Both management systems described above have several characteristics in common: forests are managed for a large variety of different non-timber and timber producing species, they have a limited impact on the species composition and structure of the forest and appear to be executed in a rather haphazard or casual manner (Anderson, 1988, 1990; Peters, 1996).

Peters (1996) further pointed at another important characteristic of these management systems. The change in species composition results mainly from targeting seedlings and saplings. This in contrast to silvicultural treatments frequently applied in timber management systems where the opening of the canopy by the harvesting procedure itself and by selectively removing non-commercial trees is the most important element (Whitmore, 1990). The first approach is a gradual and slow process but minimises large changes in the structure of the forest, whereas the second approach creates large changes in the structure, and thus environmental conditions within the forest.

The Neotropics also provide a few examples of more intensive management of tree species; the cultivation of commercial tree species in plantations. For example, the scarce information available in the international literature suggest that brazil nut trees grown in plantations start producing after 10 to 15 years, when they reach a diameter of approximately 20 – 25 cm, but it takes about 10 years more before they reach a normal production (Mori & Prance, 1990). Although the same authors present high production values per tree and per unit area, they also point at the importance of selecting the right areas for establishing plantations of this important amazon product. In addition, they mention that some consideration should be given to preserving the habitat for pollinators which nests mostly in secondary and undisturbed forests. They therefore suggest that in order to ensure adequate pollination, patches of forest should be left in the vicinity of the plantation. Whether this suggestion is vital or not remains to be seen because, as both authors mention in the same paper, sufficient pollinators were observed in a 3000 ha plantation in Acre, Brazil, which was surrounded by pasture (Müller, 1981), and in a much smaller plantation in a disturbed area near Manaus, Brazil (Nelson *et al.*, 1985).

The rubber tree (*Hevea brasiliensis*) is another example of a valuable Amazon tree species grown in plantations. The fate of these plantations in their native habitat, however, has been less than successful due to diseases such as the South American leaf blight. A third example in the Neotropics is provided by *Swietenia* spp. plantations which almost without exception suffer from the shoot boring insect *Hypsipyla* spp.

These experiences all point at an interesting and important question: what are the ecological constraints of domesticating tropical tree species? Although the examples mentioned above refer to species grown in plantations, the following overview will focus on those aspects of the ecology of tropical tree species which are important to take into account if one aims to increase the density of useful species in tropical rain forests. This is important to note, because the difference between increasing the density of one or more species in a species-rich ecosystem and the establishment of mono or mixed-species plantations after clearing the forest first, is likely to be more than just a difference in intensity or scale.

Ecological constraints of domesticating tropical tree species

This overview, albeit brief and incomplete, will highlight some of the attributes of the system and its inhabiting species which may limit the effectiveness of practices applied to increase the density of certain species in a manipulated natural forest stand and in so-called agroecosystems.

Plant animal interaction: pollination and seed dispersal

Most tropical tree species depend on animals for the pollination of their flowers. Some of these plant-animal relationships are highly specific, with e.g. one type of insect being responsible for pollinating the flowers of a particular tree species (Wiebes, 1979). Data of Bawa *et al.* (1985) from a lowland forest in Costa Rica illustrate the commonness and importance of pollination by animals among tropical trees. 139 or 96% of the 143 tree species surveyed on their site were pollinated exclusively by animals. From those animal pollinators medium to large-size bees were the most common pollinators, especially among trees of the upper canopy (Appanah, 1990). But apart from bees, other insect groups and even vertebrates such as bats and hummingbirds are well represented among the pollinators of tropical rainforest trees.

Animals also play an important role in seed dispersal in the tropics. Gentry (1982), for example, showed that 93 percent of the canopy tree species and 91 percent of the subcanopy trees in Rio Palenque, Ecuador, produce fruits which are dispersed by birds or mammals. At Barro Colorado Island in Panama, Croat (1978) estimated that 78% of the canopy trees and 87% of the subcanopy trees have animal-dispersed seeds. The dispersal of seeds by animals is thought to have a number of advantages for the tree. First, dispersed seeds are more likely to escape the high mortality that frequently occurs below the parent tree, either as a result of predation or competition among established seedlings. Secondly, dispersal provides a mechanism to colonise new habitats further away from the parent tree (Howe & Smallwood, 1982) and thirdly, in some cases dispersal may even position, e.g. through burying, a seed in a microsite where it will have a higher probability to germinate and establish than seeds not dispersed by animals. However, in spite of the importance of seed dispersal by animals among tropical tree species, the relationship of a particular animal disperser to a particular fruit-bearing species appears to be less specific than the relationship between tree species and their pollinators (Whitmore, 1990).

How important now are these plant-animal interactions for management activities which aim to increase the density of useful species in the system. When management changes the species composition in favour of some economically important species without seriously altering the structure and species composition of the ecosystem, pollination is not likely to be affected. But it probably will be in situation where the species composition is changed dramatically. In the latter situation the management of the pollinator population may become as important as the management of the tree population which depend on these animals for their pollination (Bawa & Krugman, 1991).

Animals clearly represent a cost in terms of the amount of fruits which are lost or damaged during dispersal. However, the advantages of animal dispersal are also important for resource managers. Especially, in the case of those species which seem to have a more obligatory relationship with the animals which disperse their seeds and in those cases where one wishes to increase the density of useful species partly by promoting or favouring natural regeneration.

Growth and survival of seedlings and saplings

It is probably safe to say that the highest mortality in the life cycle of tropical rain forest tree species occur in the seed and seedling stage. Howe *et al.* (1985), for example, found that 98% of the seeds of *Virola surinamensis*, a large canopy tree of the Neotropics, are destroyed by rodents and weevils during the first twelve weeks after dispersal.

The high mortality of seeds and seedlings, especially near parent trees, prompted Janzen (1970) and Connell (1971) to suggest that seed and seedling predation might be related to the density and/or distance to the parent tree. According to both authors, seed predation is highest near the maternal parent tree, causing survival to increase with distance from the parent. Under these conditions, the product of seed density and survival is thought to yield a peak in recruitment at some distance away from the parent. The low recruitment near the parent now reduces the potential for single species dominance in the community and may be responsible for maintaining species diversity in tropical rain forests.

This phenomena, of course, would also have major implications for management practices which aim to increase the density of useful species in the system. However, twenty five years after this model was postulated the extent to which these mechanisms operate in tropical rain forests are still not fully understood (Hammond & Brown, 1997) and experiences with indigenous forest management systems described above, suggest that in species-rich forests there is still scope for increasing the density of some desired species without immediately facing this problem.

Another aspect important for domesticating tropical rain forests and/or their species is the build-up of pests and diseases which appear to be common in perhumid lowland tropical climates. According to Leakey & Newton (1994) scarcity or low density can even be seen as a strategy to avoid damage by pests and diseases. Or in other words, the build-up of pests and diseases may act as an ecological barrier to changes in the species composition of tropical rain forests in favour of one or just a few species.

Conclusions

Since the late 1980's, when sustainable extraction of non-timber forest products from tropical rain forests was first advocated as a strategy to best conserve the diversity of these forests, data have become available which allow us to evaluate some of the assumptions which underlie this strategy. The data suggest that commercial extraction of NTFP from species-rich tropical rain forests often result in over-exploitation and low productivity of the collector. However, the assumption that the extraction of NTFP has no measurable impact on the biological diversity of the system seems to be true in most cases. The reason for that may be that in general the extraction of NTFP does not greatly affect the structure and functioning of these species-rich ecosystems, and hence is less likely to result in large changes in the species composition as for example high intensity timber extraction does.

The daily income generated with the extraction of NTFP is often low because more labour time is expended in lengthy and frequently interrupted collection activities, which strongly reduces the efficiency of labour. This, of course, follows from the high species-diversity of these ecosystems which result in a low density of conspecifics and hence a low product availability per unit area.

Increasing the density of useful species in the forest may help to reduce the impact of extraction on the species providing the resource and may increase daily income of product collectors. Indigenous forest management systems, such as manipulating the succession in abandoned agricultural fields and more gradually through the selective removal of undesired species and the planting and protecting of useful ones in otherwise undisturbed or structurally unchanged forest, provide examples of how this management objective can be achieved.

Tropical rain forest and their tree species differ in some important ways from forests in temperate climates and these differences have important consequences for resource managers who aim to increase the density of useful species in the forest ecosystem. A brief overview of some of the key characteristics of tropical tree species suggest that pollination, seed dispersal, high predation and mortality of seeds and seedlings, the build-up of pests and diseases will all have to be taken into account when management practices are applied which aim to increase the density of the economically important species in the system.

Finally we may conclude that extraction of NTFP from species-rich tropical rain forests may reconcile conservation and economic development. But only after increasing the availability of forest resources through the application of silvicultural practices.

Acknowledgement

I would like to thank Alan Bojanic, Armelinda Zonta and Wim Dijkman for valuable discussions during the preparation of this manuscript.

References

Allegretti, M., 1990. Extractive reserves: an alternative for reconciling development and environmental conservation in Amazonia. In: A.B. Anderson (Ed.), Alternatives to Deforestation: Steps towards Sustainable Use of Amazonian Rain Forests. Colombia University Press, New York, pp. 252–264.

Appanah, S., 1990. Plant-pollinator interactions in Malaysian rain forests. In: K.S. Bawa & M. Hadley (Eds.), Reproductive Ecology of Tropical Forest Plants. Man and the Biosphere Series 7, UNESCO and Parthenon Press, Paris, pp. 85–101.

Anderson, A.B., 1988. Use and management of native forests dominated by açai palm (*Euterpe oleracea* Mart.) in the Amazon estuary. *Advanced Economic Botany* 6: 144–154.
Anderson, A.B., 1990. Extraction and forest management by rural inhabitants in the Amazon estuary. In: A.B. Anderson (Ed.), Alternatives to Deforestation: Steps towards Sustainable Use of Amazon Rain Forest. Columbia University Press, New York, pp. 65–85.
Ashton, P.S., 1984. Biosystematics of tropical woody plants: A problem of rare species. In: W.F. Grant (Ed.), Plant Biosystematics. Academic Press, New York, pp. 497–518.
Balée, W., 1987. A ethnobotanica quantitativa dos indios Tembi (Rio Gurupi, Para). *Boletin Museo Emilio Goeldi* 3: 29–50.
Balée, W., 1989. The adaptation to culture in Amazonia. In: D.A. Posey & W. Balée (Eds.), Resource management in Amazonia. Indigenous and folk strategies. *Advances in Economic Botany* 7: 1–21.
Bawa, K.S., S.H. Bullock, D.R. Perry, R.E. Coville & M.H. Grayum, 1985. Reproductive biology of tropical lowland rain forest trees II. Pollination systems. *American Journal of Botany* 72: 346–356.
Bawa, K.S. & S.L. Krugman, 1991. Reproductive biology and genetics of tropical trees in relation to conservation and management. In: A.Gomez-Pompa, T.C. Whitmore & M. Hadley (Eds.), Rain Forest Regeneration and Management. Man and the Biosphere Series 6. Parthenon Publications, Paris, pp. 199–236.
Boom, B.M., 1985a. 'Advocacy botany' for the Neotropics. *Garden* 9 (3): 24–32.
Boom, B.M., 1985b. Amazon Indians and the forest environment. *Nature* 314: 324.
Boot, R.G.A. & R.E. Gullison, 1995. Approaches to developing sustainable extraction systems for tropical forest products. *Ecological Applications* 5(4): 896–903.
Browder, J.O., 1992. The limits of extractivism: tropical forest strategies beyond extractive reserves. *Bioscience* 42: 174–182.
Connell, J.H., 1971. On the role of natural enemies in preventing competitive exclusion in some marine animals and in rain forest trees. In: P.J. Den Boer & G.R. Gradwell (Eds.), Dynamics of Populations. PUDOC, Wageningen, pp. 298–310.
Croat, T.B., 1978. Flora of Barro Colorado Island. Stanford University Press, La Jolla, 943 pp.
De Beer, J.H. & M.J. McDermott, 1989. The economic value of non-timber forest products in Southeast Asia. Netherlands Committee for IUCN – The World Conservation Union, Amsterdam, 198 pp.
Dijkman, M.J., 1951. Hevea: Thirty years of research in the Far East. Florida University Miami Press, Coral Gables.
Gentry, A.H., 1982. Patterns of neotropical plant species diversity. *Evolutionary Biology* 15: 1– 84.
Gentry, A.H., 1988. Tree species richness in Amazonian forests. Proceedings U.S. *National Academy of Sciences* 95: 156–159.
Gomez-Pompa, A., J.S. Flores & V. Sosa, 1987. The "pet-kot": A man-made tropical forest of the Maya. *Interciencia* 12: 10–15.
Hall, P. & K. Bawa, 1993. Methods to assess the impact of extraction of non-timber tropical forest products on plant populations. *Economic Botany* 47: 234–247
Hammond, D.S. & V.K. Brown, 1997. Disturbance, phenology and life-history characteristics: factors influencing frequency-dependent invertebrate attack on tropical seeds and seedlings. In: D.M. Newbery, N.D. Brown & H.H.T. Prins (Eds.). In: Population and Community Dynamics in the Tropics. Blackwell Scientific Publishers, Cambridge, (in press).
Howe, H.F. & J. Smallwood, 1982. Ecology of seed dispersal. *Annual Review of Ecology and Systematics* 13: 201–228.
Howe, H.F., E.W. Schupp & L.C. Westley, 1985. Early consequences of seed dispersal for a neotropical tree (*Virola surinamensis*). *Ecology* 66: 781–791.
Janzen, D.H., 1970. Herbivores and the number of tree species in tropical forests. *American Naturalist* 104: 501 – 528.
Lamb, D., 1991. Combining traditional and commercial uses of rain forests. *Nature & Resources*, Vol. 27(2): 3–11
Leakey, R.R.B. & A.C. Newton (Eds.), 1994. Domestication of tropical trees for timber and non-timber products. Man and the Biosphere Digest 17, UNESCO, Paris, 94 pp.
Mori, S.A. & G.T. Prance, 1990. Taxonomy, ecology, and economic botany of the Brazil nut (*Bertholletia excelsa* Humb. & Bonpl.: Lecythidaceae). *Advances in Economic Botany* 8: 130–150.
Müller, C.H., 1981. Castanha-do-Brasil; estudos agronômicos. Documentos 1, Empresa Brasileira de

Pesquisas Agropecuárias (EMBRAPA), Centro de Pesquisas Agropecuário do Trópico Umido, pp. 1–25.

Nelson, B.W., M.L. Absy, E.M. Barbosa & G.T. Prance, 1985. Observations on flower visitors to *Bertholletia excelsa* H.B.K. and *Couratari tenuicarpa* A.C. Sm. (Lecythidaceae). *Acta Amazônica* 15 (suppl.): 225–234.

Padoch, C., J. Chota Inuma, W. De Jong and J. Unruh, 1985. Amazonian agroforestry: A market-oriented system in Peru. *Agroforestry systems* 3: 47–58.

Peters, C.M., 1996. The ecology and management of non-timber forest resources. World Bank Technical Paper 322. The World Bank, Washington, 157 pp.

Peters, C.M., A.H. Gentry & R.O. Mendelsohn, 1989. Valuation of a Amazonian rain forest. *Nature* 339: 655–656.

Siebert, S.F. & J.M. Belsky, 1985. Forest-product trade in a lowland Filipino village. *Economic Botany* 39: 522–533.

Vazques, R. & A.H. Gentry, 1989. Use and misuse of forest harvested fruits in the Iquitos region. *Conservation Biology* 3: 350–361.

Whitmore, T.C., 1990. An introduction to tropical rain forests. Oxford University Press, New York, 226 pp.

Wiebes, J.T., 1979. Coevolution of figs and their insect pollinators. *Annual review of Ecology and Systematics* 10: 1–12.