RELEVANCE OF LOW-TECH RESEARCH IN BOTANY IN INDIA

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I would like to convey my sincere thanks to the Executive Council of the Indian Botanical Society for electing me as the President for the year 2010. This address is the outcome of experiences gained during my career as a researcher, teacher and supervisor for research students involving continuous interactions with my teachers, colleagues and students. I acknowledge the inputs from all of them over the years. I would particularly like to thank Professor N.S. Rangaswamy and Professor H.Y. Mohan Ram with whom I have had the privilege of intense and stimulating academic interactions for over 45 years. I thank ATREE for facilitating my research activities after my retirement from Delhi University.

Today I have decided to talk on a subject on which I feel strongly, although I am not an expert on many of the areas I am covering. Until 1970s the funding for research in our country particularly for plant sciences was very limited. Nevertheless substantial and significant contributions were made in many Universities and Research Institutions in traditional areas such as morphology, embryology, taxonomy, ecology, mycology and cytogenetics covering almost all groups of plants. Most of these studies were carried out with limited resources and infrastructure. I call this type of research as low-tech research. Internationally reputed Schools were established in different disciplines of Botany in various Universities (see Johri 1995). Just to mention a few of these schools about which I am familiar: embryology and experimental embryology from the University of Delhi, morphology from Meerut University, ecology and phycology from Banarus Hindu University, mycology and phycology from the University of Madras, taxonomy from Calicut University, and cytology and cytogenetics from the University of Calcutta. Apart from generating extensive data in these traditional areas, many of the research contributions from some of our Institutions were outstanding and had a significant international impact on subsequent researches in the area.

During the last three decades, there has been a steady and significant increase in the funding for research. More and more research projects are being sanctioned by the Department of Science and Technology (DST), Department of Biotechnology (DBT), Ministry of Environment and Forests (MoEF), Council of Scientific and Industrial Research (CSIR) and University Grants Commission (UGC). The fellowship amount for research scholars has also increased substantially over the years. This improved funding has resulted in better infrastructure in most of our Universities and Research Institutions. In the light of these improvements, it was expected that, apart from initiating research in modern disciplines such as biotechnology, molecular biology and molecular genetics, research in traditional disciplines would be intensified and more significant contributions would emerge. More importantly, the techniques of modern disciplines were expected to be integrated with traditional disciplines for a better understanding of the structure of plants in relation to their function and evolution.

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However, our research output in traditional disciplines has steadily gone down in recent decades. Some of the traditional schools which had gained international recognition have decimated over the years. The Vice-chancellors of many of our Universities and Directors of Research Institutions tend to look down on traditional disciplines and there is lack of appreciation of their relevance in the present day teaching and research. Most of our young botanists in recent years have shown greater interest in doing research in areas of modern disciplines such as molecular biology, biotechnology, molecular genetics, genetic engineering, bioinformatics and computer modeling. The field botanists who formed the backbone of many of the traditional disciplines have become rare. Research in modern disciplines requires expensive equipment and infrastructure and I call this as high-tech research. The extent of funding to these high-tech areas is also disproportionately large compared to traditional disciplines. It is not my intention to go into the reasons for such a disparity in funding. Also I want to make it clear that I am not against these modern high-tech areas of research. They are certainly important for a comprehensive understanding of plants in relation to their function and for commercial exploitation. Research in these high-tech areas is also highly relevant to keep our research competitive at international level. However, these high-tech research areas cannot develop in isolation without comparable advances in traditional disciplines. Also, the number of laboratories with required facilities to carryout research in high-tech areas is limited; only a small number of research students can get into these areas.

There are a number of low-tech research areas in Botany which do not require expensive instrumentation and other infrastructural facilities, but are equally challenging and important as high-tech research areas. Today I want to highlight the relevance of some of these low-tech research areas which have to be taken up urgently if our country has to catch up with Western countries in building a sound database on our plant wealth.

MAJOR CHALLENGES FACING THE COUNTRY IN THE COMING DECADES

One of the major challenges we have to face in the coming decades is the management of our biodiversity. Realizing the importance of biodiversity, UN General Assembly has declared 2010 as the International Year of Biodiversity. We are fortunate to inherit a vast biodiversity with a high component of endemic species (Rao 1994, Bawa 2010, Uma Shaanker *et al.* 2010). Our land mass encompasses four of the mega-diversity hotspots of the world - the Western Ghats, the Himalayas, Indo-Burma (northeast India south of Brahmaputra) and Sundarland (Nicobar Islands). Although we cover only 2% of the land area, our biodiversity is about 7.5%.

DOCUMENTATION OF BIODIVERSITY

The three mantras of biodiversity have been: documentation, conservation and sustainable utilization. "One of the first steps towards a successful national biodiversity strategy is to conduct surveys to find out what biodiversity exists, its value and importance, and what is endangered" (Conservation of Biological Diversity 2000). Therefore, the first step towards a successful management of our biodiversity is the documentation of our biodiversity. This requires extensive surveys to collect, name and describe all the new species, and analyze their value and importance. This is a huge task particularly in the North-East, and Andaman and Nicobar islands, where our surveys so far have been rather limited. The fact that over 350 new species have been described from North-East India alone during the last decade highlight the number of species that remains to be described and the enormity of the task to be undertaken. According to one estimate, the number of species reported so far in India is: angiosperms -18,500, pteridophytes - 1,100, bryophytes - 2,600, lichens - 2,500, fungi - 23,500, algae - 2,500, and bacteria 900; total - over 50,000 species (see Khoshoo 1995, see Uma Shaanker *et al.* 2010 for details of Databases available on Plant Resources of India). The most conservative estimate of the total number of species present in India is at least three times the number of species that have been described so far. Thus over 1,00,000 species are yet to be collected, named and described. The total number of species named so far in the world is estimated to be 1.8-2 million species (World Conservation and Monitoring Centre 1993, The 2005 Millennium Ecosystem Assessment Notes). Of these only 4,00,000 (0.4 million) have been named from tropical countries, although they harbor maximum number of species. Estimate for the total number of species in the world vary widely. The conservative estimate is 10-12 million species (see Khoshoo 1995). More importantly > 8 million species, yet to be described, are thought to occur in the tropics.

What type of research is needed to describe these new species? What type of expertise is needed to undertake this huge task of documenting our biodiversity? Only taxonomists will be able to undertake this job. However, the number of taxonomists available in the country is very small and is steadily declining; certainly it is not proportional to the task to be undertaken. The situation is particularly worse in lower groups of plants.

Why have we reached this state as far as taxonomy is concerned? A number of factors seem to be responsible for this state. Two of the major factors are:

TEACHING OF TAXONOMY IN UNIVERSITIES AND COLLEGES

In most of the undergraduate colleges, taxonomy is being taught by non-taxonomists and they have been successful in making taxonomy a dull and uninteresting subject right from the beginning. Even at the post-graduate level, very few Universities have appointed professional taxonomists to teach taxonomy. The teaching of taxonomy by non-taxonomists is more like testing the memory of the candidate (botanical names of plants and a few salient features of each family) rather than stimulating the student to understand taxonomic principles and their importance. Although there are field trips, they have become more of picnic trips rather than serious studies on plant taxonomy and ecology. Herbarium collections seem to be done only for completing examination formality. Even the recent Report (2010) of the Task Force constituted to make Recommendations to the Government for Strengthening of Botanical and Zoological Surveys of India (Task Force of BSI and ZSI) has also highlighted the "falling standard in taxonomy training in our Universities making it difficult for BSI to find taxonomists for recruitment". Unless we recruit competent taxonomists in our educational institutions to create interest in students in taxonomy we would never be able to fill the gap of taxonomists.

JOB OPPORTUNITIES

This is an essential prerequisite to attract enough number of talented students to taxonomic research. There have been very limited job opportunities for the taxonomists. Although Botanical Survey of India (BSI) is the nodal agency for documenting our biodiversity and one should expect a large scale recruitment of taxonomists, there is hardly any serious recruitment of taxonomists in the BSI since many years. Most of the Universities and Colleges seem to think that taxonomy can be taught even at the M.Sc. level by non-taxonomists and thus taxonomists are hardly recruited in the Colleges and Universities. Unless there is marked improvement in job opportunities for taxonomists, we cannot expect to attract more and more researchers to taxonomy.

Many initiatives are being taken to strengthen taxonomy by the DST and MoEF. Recently Bawa (2010), the Task Force of BSI and ZSI (2010), and National Consultation on 'Advancing the Science of taxonomy in India for Biodiversity Conservation' under the auspices of Ashoka Trust for Research in Ecology and the Environment (ATREE) (Bhaskaran and Rajan 2010) have made several recommendations to make taxonomy more attractive and relevant. Hopefully these recommendations would be implemented soon by concerned authorities.

DOCUMENTATION OF RARE, ENDANGERED AND THREATENED (RET), AND ENDEMIC SPECIES.

Apart from documenting our biodiversity we have to give special attention to identify endangered and endemic species. One third of our species are endemic. Identification of these endemic species and generating data on their biology has to be taken up urgently. A large number of species have been pushed into threatened category because of habitat loss and/or overexploitation. Unless we have an authentic list of such species, no effective conservation work can be undertaken. Although we have a huge list of Indian species which have been included in the red list, both by the IUCN (Rao *et al.* 2003, The IUCN Red List of Threatened Species 2008) and BSI (series of volumes on Red Data Book of Indian Plants since 1987, see also Ravikumar and Ved 2000), the list is not based on scientific data. According to the IUCN criteria scientific assessment of threatened species should be based on the following major key information:

- Actual or projected reduction in population size
- Extent of occurrence or area of occupancy.
- Population number and number of individuals in each population.
- Quantitative analysis showing the probability of extinction in the wild.

We do not have the data on these critical aspects probably on any of our red listed species. We have not even made a serious beginning to collect such information. We have to initiate studies on population biology of our endangered species. These studies should focus on population size, population distribution, population density, population growth, population structure and monitoring and mapping of populations and their ecological details. This does not mean that conservation efforts have to wait until this data is collected for all our RET species. We have to start conservation of critically endangered species and at the same time initiate urgently population level studies on our RET species.

CONSERVATION OF RET SPECIES.

Conservation biology is the scientific study of the maintenance, loss and restoration of biological diversity. It is an interdisciplinary science and requires expertise not only from different disciplines of biology such as ecology, taxonomy, population biology, population genetics and reproductive biology but also from non-biology areas such as economics and sociology.

Unfortunately, conservation efforts so far in our country (see Uma Shaanker *et al.* 2010 for ongoing conservation efforts) have been arbitrary and there are hardly any success stories. Reintroduction of endangered plant species to natural habitats has been one of the major approaches of our conservation efforts at the species level. Tissue culture technology is considered to be very useful for multiplication of endangered species for reintroduction to natural habitats. Although tissue culture is a powerful technology, it has not been used effectively so far for conservation efforts. Although laboratory protocols have been worked out for multiplication of a number of endangered species, there are very few attempts to transfer tissue-culture raised plants to natural habitats. I am aware of only three species in which tissue culture-raised plants have been transferred to natural habitats an insectivorous plant, Nepenthes khasiana (North-Eastern Hill University, Shillong), an orchid, Paphiopedilum drurii [Tropical Botanical Garden and Research Institute, Kerala (TBGRI)], and recently a critically endangered species, *Ceropigia fantastica* (Shivaji University, Kolhapur). I am not aware of the present status of transferred plants of the insectivorous plant and the orchid, in which the work was done some years back. Recently, attempts have been made to reintroduce another critically endangered species, *Semecarpus kathalekanensis*, into new sites (ATREE). Some *ex situ* conservation efforts have also been made [Foundation for Revitalization of Local Health Traditions (FRLHT) and TBGRI] on several endangered species particularly of medicinal plants but these are very limited and totally inadequate. Considerable germplasm has been stored in our seed banks particularly at the National Bureau of Plant Genetic Resources (NBPGR), but these are confined largely to crop species and their relatives.

Why do conservation efforts in our country have been of limited success? One of the major reasons is that we hardly know anything about the biology of these species, which is so essential to develop and implement effective conservation management strategies. We do not have dependable data even on the three basic questions related to conservation: what to conserve, where to conserve and how to conserve? Therefore, we have to initiate research to collect baseline data on the biology of endangered species. We also do not have such data even for most of our endemic, economically important and tree species growing in wild; such data are essential for their management, exploitation and genetic improvement.

GENERATION OF DATA ON THE BIOLOGY OF RET AND ENDEMIC SPECIES.

The stability of the species depends on effective reproduction and recruitment of new individuals to sustain populations. Major threats to biological diversity are (1) habitat loss and/or (2) overex-ploitation of the species. Whether it is habitat loss or overexploitation, they in turn affect the stability of populations/species by imposing some constraint (s) in their reproduction and/or recruitment of new individuals to the population. These constraints lead to a gradual reduction in population size. Continuous reduction in population size leads to eventual extinction of the population. Often, the population resorts to selfing as a means of reproductive assurance when its size is reduced beyond a critical number. Inbreeding for many generations leads to loss of genetic variability, inbreeding depression, progeny with reduced vigor and fitness, loss of evolutionary potential to cope with changed habitat and eventual extinction of the populations and the species. Thus, species are pushed into threatened category when deaths exceed births for a prolonged period due to some constraints in their reproduction and/or recruitment.

As mentioned earlier, successful reproduction and recruitment are the major constraints in species sustainability. Reproductive success in cultivated species is assessed on the basis of economic yield. As seeds are the economic products in most of our crop plants, reproductive success is assessed on the basis of seed production. However, in wild species reproductive success is assessed on the basis of recruitment of new individuals which is the basis of sustainability of the species. Apart from other reproductive events, reproductive success is greatly influenced by plant-animal interactions during different phases of reproduction-pollination, seed dispersal and seedling recruitment. Tropical rain forests are currently at greatest risk from reproductive failure (Wilcock and Neiland 2002). Although considerable information on reproductive ecology is available on species growing in neotropical and south-east Asian tropical forests (see Bawa and Hadley 1990), there is hardly any information on species of Indian tropical forests. Understanding of reproductive ecology of species is the key to their conservation, management and sustainable utilization (Kwak and Bekker 2006).

Reproductive ecology covers a broad spectrum of events involved in reproduction of an organism and their interaction with biotic and abiotic components of the habitat. Sexual reproduction in flowering plants involves the following major sequential events: initiation and development of flowers, development of functional ovules and pollen grains, pollination pollen-pistil interaction, fertilization, development fruits and seeds, seed dispersal, seed germination, seedling establishment and its development into adult plant. A break at any level in these sequential events, leads to reproductive failure. Identification of reproductive constraints, if any, would enable the use of suitable methods to overcome the constraints and thus facilitates optimal use of conservation resources.

In brief, the following are the basic aspects of reproductive ecology needed for effective conservation:

PHENOLOGY

Phenology is the study of the responses of living organisms to seasonal and climatic changes in the prevailing environment. In flowering plants various reproductive events such as onset of flowering, duration of flowering and fruiting, and fruit/seed dispersal follow seasonal pattern. Phenological events in a community give information of plant population dynamics and food resource availability to animals that depend on nectar, pollen, fruits and/or seeds. In some tree species, the flowering does not occur every year, but alternate years. Also the intensity of flowering may vary between trees and between years. Phenological events may vary in response to environmental changes and thus affect reproductive success. Phenology also reveals the extent of adaptation of the species to reproductive success.

FLORAL MORPHOLOGY AND SEXUALITY

Information on floral morphology is required to understand floral cues and rewards, relative position of the anthers and the stigma and possible pollinators. Although only three sexual conditions hermaphrodite, male and female are recognisable at the level of the flower, there is great variation in the sexuality of the populations and species depending on the distribution of these three types of flowers within and amongst plants in the population. Sexuality affects pollen flow and the breeding system. In some species the flowers are morphologically similar, but behave functionally as male and female flowers; such condition is called functional/cryptic dioecy and can be determined only by studying the function of the pollen and the pistil. Often, the sexuality of functionally dioecious species is reported wrongly in Floras.

POLLEN AND PISTIL BIOLOGY

These studies include the details of stigma receptivity, time of pollen release, extent of pollen fertility and the temporal details of their viability. The morphology of the stigma is correlated with a number of reproductive features such as the type of incompatibility, the details of pollen hydration and germination. At the time of pollination, pollen grains have to be viable and the stigma has to be receptive. They are critical for the reproductive success of the species. Several species show protandry/protogyny and this would affect pollen flow and may also affect the mating system. Some of these features may lead to pollination constraints.

POLLINATION BIOLOGY

Pollination is the transfer of pollen from the anther to the stigma. This is one of the critical events that determines reproductive success of the species. Successful pollination is an essential prerequisite for fruit and seed set. Plants have developed an amazing adaptation to achieve pollination. It is important to distinguish pollinators from floral visitors which do not bring about pollination. In many of the investigations pollinators are recognized on the basis of the presence of pollen load on the visitors. This may often turn out to be incorrect. It is always safer to distinguish pollinators from non-pollinating visitors on the basis of pollen transfer to the stigma/fruit and seed set following the visit to a virgin flower. Plant species may be generalists or specialists (Waser *et al.* 1996, Waser and Ollerton 2006). The concept represents two ends of a continuum between extreme generalization and obligate specialization. Obligate specialization, in which the plant species depends on a single pollinator and show reciprocal specialization between plant and pollinator, is found only in a few species such as figs, yuccas and several orchids (Waser and Ollerton 2006). Broadly, generalists attract a number of animal species for pollination and specialists use only one or a few animal species for pollination. Plants that depend on a single pollinator species are at a higher risk of extinction; if one of the partners becomes rare or absent, the other is also bound to fail. It also binds both the partners for spreading into new areas. Plants with generalized pollinator systems are resilient to the loss of some pollinator species since some others may take over pollination services.

Pollination is a dynamic process and pollinators show temporal and spatial variation in principal pollinators. Pollination limitation (reduction in seed production by inadequate deposition of pollen) is quite common (Burd 1994, Larson and Barrett 2000, Wilcock and Neiland 2002) and may act as a serious constraint for seed production. Pollination limitation may be the result of several ecological disturbances such as habitat fragmentation, presence of co-flowering plant species and introduction of alien species. Detailed information on pollination limitation is necessary to come up with an effective strategy to overcome the limitation (Wilcock and Nieland 1998, Spira 2001).

POLLEN-PISTIL INTERACTION

Following successful pollination, pollen grains have to germinate on the stigma and the resulting pollen tubes have to grow through the tissues of the stigma and style; eventually pollen tubes have to enter the ovule and the embryo sac, and release male gametes for fertilization. Successful completion of pollen-pistil interaction and fertilization are essential for seed development. Failure to complete pollen-pistil interaction may be a limitation particularly in self-incompatible and dioecious species.

BREEDING SYSTEM

Breeding system is the mode of transmission of genes from one generation to the next through sexual reproduction. It largely reflects the extent of selfing/crossing in a species. Plants have evolved a number of devices to encourage outbreeding and to discourage inbreeding. It is necessary to understand the nature of the breeding system of the species as it determines the genetic variability in the population and thus its sustainability.

FRUIT AND SEED BIOLOGY

Seed production is essential for the

long-term sustainability of plant populations. As units of gene flow, they help the species to spread to new areas and adapt to new environments. Reduction in seed output by failure at any level of reproductive events results in a decline in recruitment of new individuals. Therefore, fruit and seed biology is yet another important aspect of reproductive ecology which has relevance to conservation biology (Khurana and Singh 2001, Moza and Bhatnagar 2007). Some of the important aspects of fruit and seed biology are: extent of fruit/seed production and their dispersal, the extent and longevity of soil seed bank, seed viability, seed germination, the level of seed and seedling predation and seedling establishment (Hall and Lulow 1997, Bustamante and Simonetti 2000). Seed and seedling predation by insects/rodents may become an important constraint for seedling recruitment.

Seedling recruitment is one of the major constraints in sustaining population. The biology of seeds present in the soil seed bank, particularly temporal details of their dormancy, viability, longevity and germination, is more important for reproductive success of the species than the behavior of seeds maintained in the laboratory. In many species although seed production is abundant, seedling recruitment is limited due to many factors such as overexploitation by humans particularly in species yielding non-timer forest products, loss of seed viability, and seed and/or seedling predation. All the parameters described above contribute to the reproductive success and sustainability of the species. Applications of the knowledge gained from reproductive failure/limitation will have important relevance for risk assessment and its mitigation.

SPECIES RECOVERY

Conservation is a complex and difficult issue particularly in developing countries as it has to be environmentally sound but in tune with social justice and poverty alleviation. Conservation efforts are being increasingly directed towards habitats, ecosystems and communities (Uma Shaanker *et al.* 2010) rather than on specific species. Although this is the ideal approach, it is a difficult and expensive approach, and under certain conditions may not be realistic (Bakker and Berendse 1999). However, recovery of most critically endangered species may be more effective at the level of the species rather than at the community (Wilcock and Neiland 2002).

In Western countries conservation efforts have been more systematic and many red-listed species have been effectively recovered and have been delisted from the red-data book. Interestingly, plant species that have been successfully recovered seems to be those which are best studied (Kwak and Bekker 2006). In India, to my knowledge, there is not even a single endangered species which has been successfully recovered and delisted from the red data book.

CONCLUDING REMARKS

Although the need to rejuvenate taxonomy and to train a large number of taxonomists has been recognized by many reputed botanists, only some half-hearted attempts have so far been made by the MOEF and the DST by organizing some workshops on plant taxonomy. These efforts alone are totally inadequate and would not yield the required results. There has to be coordinated efforts from different organizations such as the University Grants Commission, MoEF, DST, Department of Biotechnology (DBT) and the BSI to improve the teaching of taxonomy in the Universities, to attract more research projects and research scholars to taxonomy and to create job opportunities for taxonomists. Also the taxonomists need to be trained on modern aspects of taxonomy. Recently Professor Bawa (2010) has suggested initiation of a fellowship programme that would allow taxonomists to spend one or two years at the world's major botanical gardens, herbaria and museums to get effective training to develop into a new breed of taxonomists well-versed in modern concepts and technologies. Apart from attracting talented researchers, such a program would certainly result in building up a pool of competent taxonomists in a few years.

Some multi-institutional initiatives have recently been initiated by the DBT on documentation of biodiversity in some areas and recovery of a limited number of endangered species. However these efforts are very limited and considering the number of species, and the area to be covered, many more such groups are needed to make a dent in documenting our biodiversity and recovery of threatened species. For species recovery programme, research projects of 3-5 years are not sufficient. There has to be a provision to monitor the populations for several years until they become sustainable.

Studies on reproductive ecology particularly on tropical species have gained importance in Western countries. A large number of papers on reproductive ecology of species of tropics are being published in international journals devoted to botany, ecology and conservation biology. Most of these publications are on species of South-East Asian and neo-tropical forests. The number of laboratories working in India on reproductive ecology is very few. Researchers need to be encouraged to take up reproductive ecology particularly on our endangered and endemic species. One of the advantages of taking up research in these areas is that it does not require expensive infrastructure or equipment. I do hope that more and more youngsters would take up research on some of these low-tech areas highlighted here and try to rejuvenate some of the traditional areas of research relevant to the management of our vast biodiversity.

REFERENCES

Bakker JP & Berendse F 1999 Constraints in the restoration of ecological diversity in grasslands and heathland communities. *Trends Ecol Evol* **14** 63-68.

Bawa KS 2010 Cataloguing life in India: the taxonomic imperative. *Curr Sci* **98** 151-154.

Bawa KS & Hadley M (eds) 1990 *Reproductive Ecology of Tropical Forest Plants*. UNESCO, Paris and Parthenon Publishing Group, Carnforth, UK.

Bhaskaran A & Rajan PD 2010 Advancing the science of taxonomy in India. *Curr Sci* **99** 157-158.

Burd M 1994 Bateman's principle and plant reproduction: the role of pollen limitation in fruit and seed set. *Bot Rev* **60** 83-139.

Bustamante RO & Simonetti J 2000 Seed predation and seedling recruitment in plants: the effect of the distance between parents. *Plant Ecology* **147** 173-183.

Hall KD & Lulow ME 1997 Effects of species, habitat, and distance from edge of post-dispersal seed predation in a tropical rain forest. *Biotropica* **29** 459-468.

Johri BM (ed) 1995 *Botany in India: History and Progress*. Vol I and II. Oxford & IBH Publ Co Ltd., New Delhi.

Khoshoo TN 1995 Census of India's biodiversity: Tasks ahead. *Curr Sci* **69** 14-17.

Khurana E & Singh JS 2001 Ecology of tree seed and seedlings: Implications for tropical forest conservation and restoration. *Curr Sci* **80** 748-757.

Kwak MM & Bekker RM 2006 Ecology of plant reproduction: Extinction risks and restoration perspectives of rare plant species. In *Plant-Pollinator Interactions: From Specialization to Generalization*, eds. Waser NM & Ollerton J, The University of Chicago Press, Chicago, pp 362-386.

Larson BMH & Barrett SCH 2000 A comparative analysis of pollen limitation in flowering plants. *Biol J Linn Soc* **69** 503-520.

Moza MK & Bhatnagar AK 2007 Plant reproductive biology studies crucial for conservation. *Curr Sci* **92** 1207.

Rao RR 1994 *Biodiversity in India*. Bisen Singh Mahendrapal Singh, Dehra Dun.

Rao CK *et al*. 2003 *Red List of Threatened Vascular Plant Species in India Compiled from the 1997 IUCN Red List of Threatened Plants*. ENVIS, Botanical Survey of India, Ministry of Environment & Forests, Kolkata.

Ravikumar K & Ved DK 2000 In: *100 Red Listed Medicinal Plants of Conservation Concern in Southern India: Illustrated Field Guide*. Foundation for Revitalization of Local Health Traditions, Bangalore.

Spira TP 2001 Plant pollinator interactions: a threatened mutualism with implications for the ecology and

management of rare plants. *Natural Areas J.* **21** 78-88.
Uma Shaanker U, Chandrashekara RK & Ganeshaiah KN 2010 Biodiversity in India: documentation, utilization and conservation. In: *Science in India, Achievements and Aspirations, 75 years of the Academy*, eds. Mohan Ram HY & Tandon PN, Indian National Science Academy, New Delhi, pp 160-175.
Waser NM & Ollerton J (eds) 2006 *Plant-Pollinator Interactions: From Specialization to Generalization.* The University of Chicago Press, Chicago.
Waser NM, Chittka L, Price MV, Williams N & Ollerton J 1996. Generalization in pollination systems, and why it matters. Ecology **77** 279-296.
Wilcock CC & Neiland MRM 1998 Reproductive characters as priority indicators for rare plant conservation. In: *Planta Europa: Proceedings of the Second European Conference on the Conservation of Wild Plants, eds.* Synge H & Akeroyd J, Swedish Threatened Plants Unit & Plantlife, Uppsala and London, pp. 221-230.
Wilcock C & Neiland R 2002 Pollination failure in plants: why it happens and when it matters. *Trends in Plant Sciences* **7** 270-277.