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# Conservation of Pollinator Resources in Botanic Gardens

**A. Bhattacharya**

*Department of Botany, Krishnagar Government College, Krishnagar, Nadia- 741101, India*
E-mail: *bhattacharyaashoke@rediffmail.com*

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## Abstract

This review presents the recent problems and future prospects of plant and pollinator resources in botanic gardens in the context of the role of botanic gardens for biodiversity conservation. Various anthropogenic disturbances, habitat and forage crisis, sound and light pollution, pesticide misuse, ignorance of plant-pollinator interactions in the botanic gardens are the primary concerns responsible for decline of plant and pollinator resources in botanic gardens. Several alternative procedures are to be followed have been discussed to overcome the problems for effective biodiversity conservation in botanic gardens.

***Key words*:** biodiversity, botanic garden, conservation, pollination

## Introduction

The biodiversity crisis is heightening interest in ways to conserve earth's biota. One of the conservation strategies is to conserve the plants and animals in a judicious way, not always it does mean to preserve and maintenance of endemic, exotic, and newly introduced plants from other countries; but to ensure this effectively, knowledge in floral biology and pollination, proper exploitation of biota; suitable habitat development and maintenance; supplementation of adequate floral resources; favoring the micro- and macro-environment for genetic out-crossing; enhancing the condition for pollen/gene flow must be implemented for effective conservation in botanic gardens. Role of botanical gardens are vital for biodiversity conservation. At the same time, neglect of important natural history collections needed to document biodiversity and possible contributions of global climate change to extinction rates promise to complicate efforts to conserve biotic diversity. About 25% of world's vascular plants may be threatened by extinction within 50 years (Raven, 1987). Rare plants are being found almost in every state of India. Importance of targeting plant species for conservation efforts must be emphasized, because conserving endangered and threatened plant species maximizes incidental protection of other endangered organisms. Unfortunately, our aim of conservation of plant wealth in botanic garden is nothing but the preservation of plant resources ignoring their reproductive partners, animal pollinators, floral ecology, forage theory and proper habitat management. Rather, we strictly follow only: not to touch the plants or we preserve them in glass/net houses for aesthetic purpose. The knowledge of floral ecology, plant-pollinator interaction, pollination, fertilization, and flower and fruit predation by invertebrate and vertebrate fauna should be our primary concern to ensure proper conservation of different rare, endangered and threatened plants in botanic garden. Conservation of an endangered plant species usually requires at least some knowledge of that species' biology so that effective management strategies can be devised. The lack of this information may hamper management decisions for effective conservation of various endemic or endangered or threatened species at botanic garden. In this article, we focus on the impact of flowering phenology and floral biology, inflorescence and floral morphology, floral visitors, breeding systems, seed germination, pollen biology and survival analysis of various plants of botanic garden for sustained conservation measures to be taken to conserve the plant wealth in botanic garden. Also, we address the conservation status and future prospects of pollinator decline and pollination deficits for germplasm maintenance in botanic garden.

**Flowering phenology and floral biology**

Flowering plants possess a wide array of morphological and physiological mechanisms that influence mating patterns and fertilization. Temporal separation of male and female function within flowers is one of the most widespread morphological mechanisms and is found in many co-sexual angiosperms in botanic garden. The conserved plants in botanic garden flower from different seasons of the year and their flowering viability vary from species to species. The positions of flower in canopies of large trees, light exposure in the garden have an impact on flower opening and pollen biology. The number of flowers/plant shows a great variation. Time and mode of anther dehiscence, pollen and nectar availability, volatile emission, stigma receptivity, flower colour changes have paramount significance for pollination. Adequate study and knowledge in all these phenomena are prerequisite on species by species basis.

**Floral visitors**

Many insect species regularly visiting the flowers of the plants in garden showed variation in their relative abundance and forage behaviour. The pollen carrying capacity and contact with stigmas by a particular insect species is plant specific and all the insect visitors of a plant might not be considered as pollinators. Among the insects, screening of effective pollinators for plants of garden having conservation interest is a powerful study. The most important group of insect visitors to the flowers in garden, with respect to frequency of visits should be identified in garden premises.

**Breeding systems**

Results of the breeding experiments based on garden plants may reflect the general reproductive behaviour and mating system of conspecific plants in the garden. Fecundity rate, apomixis and parthenogenesis tests should be performed. A continuous bagging process during flowering period reveals the type of pollination (autogamy, allogamy, xenogamy and geitonogamy) and compatibility nature of plants in the garden.

**Seed germination, pollen production, pollen viability and P/O ratios**

The extent of seed germination percentages of various plants in botanic garden might reflect the basic habitat requirement for better establishment of plants in altered environment. The proper seed storage by avoiding fungal infestation and establishing the seed bank in every botanic garden may be one of the good strategies for effective conservation. The number of pollen grains per flower and per plant, the viability of grains and P/O ratio show a great variation according to species, habitat and environmental factors. As these parameters are indices of reproductive ability of any flowering plant, so, the studies on these aspects may provide some useful data for evaluating conservation strategy.

**Survival analysis**

The mortality density, assessing the factors responsible for plantlets' mortality, extent of natality and evaluating 'environmental sieve' in the period immediately following the establishment of the plantlets in the garden should be followed. The peak of mortality density for each species in the garden must be determined; otherwise many rare, endangered and threatened plant species could not be maintained in botanic garden.

**Conservation status**

Information from the monitoring of plants of garden for several years could be summarized in an updated diagnostic of different species as follows:

(a) Number of individuals: Plant and pollinator population decline is estimated by regular visits to field sites of garden.

(b) Population regeneration: Estimation of seed bank reserve indicates the soil vouchers from the study sites where seeds remain viable. The soil vouchers in and around conserved plants of the garden should be analysed to know the regeneration potential of seeds and the seed viability should also be tested.

(c) Competition and predation: Competition with the same species for the services of the pollinators may reduce the number of plants as well as their pollinators having conservation interest. Leaf feeding by herbivores, fungal growth on mature seeds, flower buds and pollen affect plants' sustenance and reproduction.

(d) Impact of human activities: Constructing highway roads near botanic gardens, multistoried buildings, parks, monuments and continuous driving of vehicles, dumping carloads, use of artificial light and sound box in and around garden are the factors to assess conservation status.

**The value of pollinators**

Pollinators ensure seed production and provides for healthy plants grown in gardens and other urban and rural areas. Worldwide, of the estimated 1,330 crop plants grown for food, beverages, fibers, condiments, spices, and medicines, approximately 1,000 (75%) are pollinated by animals (Raven, 1987). It has been calculated that pollinators deliver one out of every three mouthfuls of food we eat, and beverages we drink. Pollinators are essential components of the habitats and ecosystems that many wild animals rely on for food and shelter. Approximately 25% of birds include fruit or seeds as a major part of their diet. Plants provide egg laying and nesting sites for many insects. Providing services through imported pollinators, encouraging local pollinator populations to grow in botanic garden, or both can offset the inadequacy of pollinator forces for production of healthy plants in botanic garden. However, cost-benefit analyses for pollination services in garden are not readily available. Olmstead and Woolen (1987) estimated that, when pollination services were provided to increase the seed production amounted to about a 600% return on investment. These values are representative of the scale of the value of pollination, although a detailed economic analysis based on the different systems has yet to be carried out. When studying apple production, Kevan (1997) calculated roughly that providing about one hive of honeybees per hectare resulted in about one extra seed per apple, which produced larger and more symmetrical apples. The cost of pollination services at that time was about 1% of production costs, and the greater yield represented a return to the grower of 700% of the cost of pollination services. Cane (1996) assessed the value of individual wild bees as pollinators. These findings represent valuable and practical approaches to evaluating pollinators as production cost with huge potential benefits. Unfortunately, the economics of bee culture and garden plant based seed production seem to have been set artificially by the high cost of the alternative of hand pollination in many countries. This is to state that none of the processes (pollinator introduction, bee colony placement and maintenance, alternative hand pollination, addition of pollen/pollinator supplements) are followed in botanic garden to maintain rich genetic diversity.

**Pollinator crisis: a recent issue**

Despite the importance of pollinators, the ever-expanding conversion of landscapes to human uses adversely affects their habitats. A growing body of evidence indicates that these beneficial creatures are in serious decline, due to loss, modification, and fragmentation of habitat, and the excessive use of pesticides. The risk of losing the essential role of pollinators, required for the successful propagation of plant communities and wildlife habitats is real. The decline in pollinators must be reversed now, before a crisis occurs. As plantings have grown larger, the need for concentrated pollinators at bloom time has grown. At the same time populations of many pollinators has been declining, and this decline has become a major environmental issue today. Monoculture needs very high populations at bloom, but can make the area quite barren or even toxic when the bloom is done. The study of pollinator decline is also interesting to some scientists, as pollinator have the potential to become a keystone indicator of environmental degradation. Any changes in their abundance and diversity may influence the abundance and diversity of the prevailing plant species. Today it seems that pollination systems in most of the botanic gardens are threatened by the inadequacy of sustainable managed, indigenous, or imported pollinators. Pollinator shortages can adversely affect the plant population in garden. Various garden plants are suggested as practical starting places for conservation studies of the effects of pollinator declines, with emphasis on the type of data are to be required based on botanic gardens. The oldest recorded examples of pollination deficit in plants are for figs, *Ficus sycomorus* (Amos ca., 760 B.C.) and for date palm, *Phoenix dactylifera*, and Smyrna figs, *Ficus carica* (Herodotus, 485-425 B.C.). Theophrastus (372-287 B.C.) recorded the lack of seeds in Egyptian figs. Galil (1967) noted that there were no wasps associated with figs from ancient tombs and how the plants spread beyond the reaches of its pollinators is unknown. For the unfertilized fruit to develop, it must be scraped in the manner described by Theophrastus (372-287 B.C.) and Galil (1967), often with a special knife (Henslow, 1892; 1902; Keimer, 1928). Depending on the translation, Amos (760 B.C.) describes himself variously as a fig scraper, piercer, dresser, or gatherer. Nevertheless, whatever his occupational designation, he clearly understood how to produce sycomore figs without pollinators. The date palm is dioecious and appears to be pollinated by wind and bees (Free, 1993; Roubik, 1995). Because male palms are not fruitful in the sense of agricultural production, only female palms have been retained. The result, even about 3000 years ago in Mesopotamia, was that hand pollination-using male inflorescences taken to the female trees were necessary (Tylor, 1891; Meeuse, 1981). Herodotus (485-425 B.C.) also described this practice; however, he was under the impression that it also involved a gallfly, and he mixed the techniques used for the anthropogenic pollination of dates and *F. carica.* Pollination was probably associated with festivals of spring and fertility in the region at the time of the Prophet Mohammed, who reportedly discouraged such festivals and only reluctantly recognized the need to hand-pollinate dates (Margoliouth, 1905; Fraser, 1935). The best pollination results today are obtained by tying dehiscent staminate inflorescences into the pistillate inflorescences of female palms (McGregor, 1976; Mbaya and Kevan, 1995) or by other artificial means. In addition, both Herodotus (485-425 B.C.) and Aristotle (350 B.C.) had some understanding of the role of bees in pollination. By the mid-18th century, the process of pollination was better understood (Knuth, 1909), who reported that even Linnaeus spoke of a special 'messenger of love' needed to fertilize the flowers. More recently, labor costs for hand pollination are rising sharply, found a solution to its shortage of pollinators for oil palm, *Elaeis guineensis*. Syed (1979) studied the pollination of this important plant and worked out the relationship between the pollinating weevils, *Elaeidobius* spp., and the inflorescences of the male and female palms. After careful screening and quarantine, *Elaeidobius kamerunicus* could be released in many botanic gardens for oil palm pollination, where it can rapidly establish. The result continues to be the sustainable and sufficient pollination of garden plants whose harvests exceed than past. Another example of placing pollinators into a novel habitat to enhance fruit production is the introduction of bees into glasshouses to pollinate the plants. Artificial pollination with electric vibrators (Kerr and Kribs, 1955) is a costly method that is no longer used, whereas buzz pollination (Buchmann, 1983) by bumblebees produces superior fruit. Morandin (2000) describes the efforts being made to solve the remaining technological problems related to greenhouse pollination. Although it may be argued that these examples are special cases and that the pollinator deficits are artificial, they serve to illustrate that, when pollinator forces are insufficient, there may be inexpensive, effective alternative methods of solving problems related to pollinator deficits in botanic garden. The pioneering work of Bohart (1972) and Hobbs (1967) has given rise to the multimillion-dollar industry of '*Megachile* culture,' whose huge economic benefits are described by

Olmstead and Woolen (1987). *Megachile, Apis spp., Vespa, Xylocopa, Ceratina* and some other members of Thysanoptera, Hymenoptera, Lepidoptera, Diptera, Coleoptera some birds and bats do pollinate the plants of botanic garden. Bohart (1957) also recognized the problem of providing adequate pollination to alfalfa seed production, which led to the commercial development of practices for encouraging and maintaining pollinators other than honey bees. As a result of the subsequent reduction in nesting habitat, there are too few pollinators to provide effective pollination for plants except those at the peripheries of botanic gardens. The contemporaneous decline of fruit or seed production of plants of botanic garden has been attributed to changing ornamental practices, including the use of insecticides. Habitat destruction has also been a problem in the pollination of some wild angiosperms of our garden. The management of plantations included the removal of rotting vegetation, the substrate in which the pollinating agents undergo larval development (Winder, 1977), and yield reductions ensured. By purposely-placing appropriate plant material such as banana (Young, 1982) or palm trunks (Ismail and Ibrahim, 1986), adequate pollinator forces can be encouraged and maintained in our garden. The impacts of habitat destruction, city pollution, paucity of pollinators, failures in plant reproduction, recruitment, and difficulties of regeneration of plants in garden might lead to the reduction in number of useful plant population in botanic garden. Colony mortality and lack of intensive management have made it more difficult to keep bees for pollination of plants of botanic garden. The role of beekeepers has been ignored and declined (Siebert, 1980), as has the number of colonies should be kept all over the garden. Other pests also threaten to reside bees inside garden. Pollination has been adversely affected, and researchers have reported difficulties in sustainable use and conservation of plant resources in botanic garden. Economic analyses of the effects of parasitic mites are much needed for garden plant conservation per se and for the ancillary benefits of pollination. The adverse effects of pesticides on pollinators are well understood, especially from a toxicological viewpoint (Johansen and Mayer, 1990). Intensity of mutated ornamentals cultivation in our garden has also been shown to correlate with lower (by about 50%) populations and diversity of insect pollinators due to lack of adequate floral resources. Kevan (1999) presents more details on the impact of hybrid sterile ornamentals on pollinator resources. The economic impacts of pollinator declines have not been well documented for the maintenance of plants in botanic gardens; we think it can be safely assumed that many local economies are being affected. Several works have attempted to illustrate the severity of pollinator declines (Buchmann and Nathan, 1996; Matheson *et al*., 1996; Kearns, *et al*.; 1998; Kevan, 1999), the problem has generally been ignored. For this reason, it is appropriate to ask the following questions from the point of view of documentation: 'Are pollinator declines real?' and 'Do they have economic consequences for garden plants?' We would not only answer both questions in the affirmative, but we also believe that the problem is extremely serious, with far-reaching consequences for conservation, agriculture and global food production. However, even the most obvious example of honeybee (potential pollinators for various garden plants) pests and diseases should be carefully examined.

**Possible causes of pollinator decline in botanic gardens**

***Anthropogenic factors***

Human activities are apparent everywhere including botanic gardens and their potential effects on beneficial insect populations would seem to be obvious. Claims for widespread declines of invertebrate pollinators are plausible but inadequately documented in botanic gardens. For instance, insecticides are applied on the plants of garden and on other parks, mosquito-ridden places, etc. The broad-spectrum insecticides that are commonly used (and abused!) are often as toxic to beneficial insects as they are to the target species (Johansen and Mayer, 1990). On the other hand, it may be that plant losses from chronic herbicide use are, in fact, driving losses of pollinator species, and not vice versa. Undocumented sites of hedgerows, garden margins, waste places provide nesting habitat for some native pollinators. Removal of these often-unappreciated habitats has been associated with dramatic declines in pollinator fauna of botanic gardens. A proportion of land area has been over cleaned, converting rich arrays of habitats into aesthetic sites, car parking sites, houses, office complexes, etc. Urbanization not only removes habitat directly but also isolates and fragments the land that it does not degrade or assimilate. The attributes, extent, and permanence of fragmentation effects for native pollinator faunas and their flowers, however, are barely understood. However, the effect of human industry on pollinators may not be so clear-cut (Bohart, 1972). The clearing of forests has opened up previously shaded, humid habitats for many sun-loving pollinators and their plants. Wooden fences, barns, and even stonewalls provide substrates for pollinators that nest above ground. Where national plants and their flowers have been removed or displaced, they have sometimes been replaced, in equal or greater numbers, by introduced species in flower and vegetable gardens, and disturbed garden. Although some of these flowers are nothing more than the sterile fabrications of plant breeders, in other cases exotic plant species supply novel resources to pollinators with unknown consequences. The brief bursts of flowering (e.g., by orchard species) may provide superabundant resources for one life stage of a pollinator, but be unable to support all the stages of its life cycle. Such short-lived plants may also favor one species at the expense of others. Clearly, some of invertebrate pollinators, probably the vast majority, are not inextricably linked to botanic gardens and reserves. We fear that what balance, extent, and kind of human activities are compatible with their persistence?

***Loss of habitat and forage***

The push to remove hedgerows and other unproductive sites in garden area removes habitat and homes for pollinators. Reckless driving and parking of cars, scooters and other vehicles, setting up of different festivals, flower show, exhibitions, many unwanted gatherings, meetings, crowd of local people for recreation and morning walk, over cleaning of certain sites in botanic garden premises may make the garden attractive and ultramodern but they remove pollinator habitat at the same time. The plants which are very good for pollinators have been disappearing for the development of pave or build over garden areas of pollinator habitat. Migratory pollinators, such as butterflies and some birds depend on nectar corridors for their annual migration, but the development practices of botanic garden have disrupted some of these vital corridors. Clear-cut logging, especially when mixed plants are replaced by uniform planting, causes serious loss of pollinators, by removing necessary bloom that feeds bees early in the season, and by removing hollow trees used by honeybees, and dead stubs used by many solitary bees.

***Suitable habitat crisis***

We cannot assume a priority that we know what constitutes 'habitat' from the perspective of an invertebrate pollinator. The important invertebrate pollinators have holometabolous life cycles, with discrete larval stages whose mobility and habitat requirements are dramatically different from those of the winged adult. Conservation initiatives have sometimes been slow to consider the needs of different life-cycle stages. For example, many conservation-minded researchers of botanic gardens advocate planting nectar plants for bees and butterflies but then fail to foster their larval host plants. Bees pose a slightly different problem e.g., immature bees have no dispersal potential, whereas adults are expert for pollen/gene dispersal. Although we lack evidence for the flight range potentials of smaller bodied bee species, we know that those of honey bee size can, if necessary, readily forage at a distance of 1 km or more from their nesting sites. Hence, invertebrate pollinators do not need continuously favorable habitats to persist, just a suitably scaled patchwork that meets adult and larval needs. The concepts of 'habitat complementarities' or 'partial habitats' are broadly applicable to invertebrate pollinators in botanic gardens. Immature stages of invertebrate pollinators are generally difficult to find and impractical to sample, but, in surveys of adults, the requirements of immature must be understood and borne in mind when classifying habitat diversity, mapping habitat 'fragments,' and evaluating change in their habitats.

***Pesticide misuse***

It is a label violation to apply most insectides on plants during bloom, or to allow the pesticide to drift to blooming weeds that bees are visiting. Yet such applications are frequently done, with little enforcement of the bee protection directions. Pesticide misuse can affect bees because they have no human to move or protect them (Kevan *et al*., 1997). Widespread aerial applications of chemicals for mosquitoes, flies, grasshoppers, moths and other insects leaves no islands of safety where wild insect pollinators can reproduce and repopulate. This makes a hostile environment for bees, butterflies and other pollinators.

***Rapid transfer of parasites and diseases***

Increased international commerce within modern times has moved diseases such as foulbrood and chalkbrood, and parasites such as Varroa mites, Acarine mites, and the small Hive beetle to new areas, causing much loss of pollinators in the areas where they do not have much resistance to these pests. The fire ants have decimated ground nesting pollinators in wide areas.

***Light and sound pollution***

Increasing use of outside artificial lights, which interfere with the navigational ability of many moth species, and is suspected of interference with birds, may also impact on the pollination systems of plants of botanic gardens. Moths are important pollinating agents of night blooming flowers and moth disorientation may reduce or eliminate the plants' ability to reproduce, thus leading to long term ecological effects inside garden. This is a new field and this environmental issue needs further study. The use of microphones, occurrence of many sound boxes here and there of garden premises may lead to pollinator decline and eventually affecting the pollination and germplasm maintenance in Botanic Gardens.

**Possible solutions to the problems**

***Conservation and restoration efforts***

Efforts should be made to sustain pollinator diversity in botanic garden ecosystem by restoration of micro and macro habitat, maintenance of suitable nesting sites for pollinator resources using bee box at various sites of garden and emphasizing research on each species biology as well as plant-pollinator interaction.

***Use of alternative pollinators***

Honey bees are usually the most widely chosen insects in most managed pollination situations. However, some specialists believe they are not the most efficient pollinators, and could be replaced by alternative pollinators, such as leafcutter and alkalai bees, bumblebees etc. A wide variety of other bees can be found in the environments that are specialist pollinators. However, most of these alternative insects value as pollinators and their relationships with plants of botanic garden are as yet little known. Some think that other pollinators will in time replace the lost honeybees. Furthermore, pollinators cannot be exchanged on a one for one basis. They are not all equal. Some are generalists, some are specialists. Some have long tongues; some short. Bees may deliberately collect pollen, but have different collection techniques, which can greatly affect their efficiency as pollinators.

***Use of pollen substitutes and supplemental pollination***

Pollen is the principal source of proteins, vitamins, lipids and minerals for honeybees. Feeding pollen supplement or substitutes is one of the best practices to encourage colony growth. A pollen substitute is any material that can be fed to colonies to replace its need for natural pollen. A pollen supplement is a pollen substitute that contains natural pollen. A pollen supplement can best be described as a pollen extender. A pollen substitute is a high-protein mixture that can adequately replace pollen in the honeybee's diet, and typically includes such ingredients as soybean flour, powdered skim milk and brewer's yeast. A pollen substitute is usually a honeybee diet mixture that contains no pollen. Among the most commonly used protein sources may be soybean meal, brewer's yeast, low-lactose whey (dried) and yeast. Pollen substitutes and extenders may be fed in a moist patty, or dry. If fed in a patty, it should be placed as close as possible to the combs containing unsealed brood. Dry materials can be fed in a feedlot system but this requires protection from adverse weather conditions and good foraging conditions. The seed/fruit production of various rare and endangered plants conserved in botanic garden has long been suffering from an insufficient pollination with not enough either male or female trees in the gardens. It seems that pollen collected from either of the plants which grow abundantly at native places could be used for the supplemental pollination of rare, endangered and threatened plants of the garden to improve their fruit set. The germination rate of selected pollen should be investigated. The mixtures of different percentages of pollen+flour or pure pollen should be sprayed to the selected trees at the beginning of the flowering stage. The rate of fruit set could be studied in the naturally pollinated ones. The percentage of blank fruits obtained from natural pollinated trees could be compared with trees sprayed with the mixtures of pollen+flour or with trees sprayed with pure pollen.

***Establishment of pollen bank***

For persons doing plant pollinization, having their own pollen bank is obvious. The main advantage is that one can use as the male parent, a plant that is not in bloom at the same time as the seed plant. It is possible to cross any plant blooming in different seasons of the year. With the help of tweezers, all the anthers of a flower are removed that was previously protected with a plastic bag in order to avoid the contamination by outside pollen. All the collected anthers are put inside an empty film box. A self-adhesive label goes around the box in order to record the name of the pollen source. The drying of the anthers is quick if the film box is exposed in the sunlight outside. After anthers are dried the pollens are released, taken in gelatin vials, kept in refrigerator at various temperatures, or in liquid nitrogen for short or long term storage. It has been possible to cryopreserve the viable pollens of many plants for long time. The viability of pollen at room temperature lowers and disappears in few days; on the contrary the cryopreservation lengthens the pollen viability. Pollen of endangered plants could be stored at -20°C for some time with the aim of checking the variation of viability. The viability is tested by fluorescein diacetate (FDA); the germination by *in vitro* culture for specific time and daily percentage of germinated pollen grains and maximum lengths of pollen tubes should be checked. The germination power may decrease or increase by temperature variation during pollen storage. Therefore the cryopreservation is to be considered an important method for the maintenance of the germplasm of many rare, endangered and threatened plant species conserved in botanic gardens.

**Goal of the Pollinator Conservation Programme**

The ultimate goal of the Pollinator Conservation Program is to ensure healthy and self-sustaining populations of pollinator resources in botanic gardens. We can work towards this by promoting the conservation of pollinator insects in various ways. We can try to increase peoples' awareness of the importance of pollinators and the threats they face by producing information materials, displays, developing a regional resource center, and creating educational activities and interpretive events for adults and children. Engage people at all levels in pollinator conservation and provide them with the knowledge and confidence to do pollinator conservation projects by presenting workshops about conservation techniques, establishing demonstration sites, producing a Pollinator Conservation Handbook, and giving technical assistance.

Protect threatened and endangered plants and pollinator species and their habitat by collaborating with scientists and agency personnel to develop information required to protect threatened species and successfully implement recovery plans. Influence decision-makers and policy by preparing written comments on agency policies, working with news media to gain greater coverage of pollinator conservation, and targeting advocacy to ensure inclusion of pollinators in management decisions.

**What sort of data needs to be collected?**

Pollination has even been worked into attempts to evaluate the value of nature's services to humankind (Costanza *et al*., 1997; Nabhan and Buchmann, 1997). However, all the estimates are based on considerable guesswork. Although small information on the value of pollination to particular plants is available, there is an even greater volume of information on the effects of pollination on seed quality. The latter has not been, but could be, converted into monetary units (Free, 1993; Roubik, 1995; Cane, 1996; Kevan, 1997; Delaplane and Mayer, 2000). If pollinators are free, then an excess of pollination is of no concern except under special circumstances. If pollinators are costly, then the grower needs to know that the marginal benefits of expanding the pollinator force are at least as great as the marginal costs. Individual farmers and grower groups at local and regional levels could make good use of information about the potential for greater harvests through better pollination. Fortunately, some databases containing information on the costs and uses of pollinator services are being developed in the Pacific Northwest and California (Burgett, 1995). Nevertheless, there is a need for more studies that provide economic analyses of the relationships among pollinators, relevant seed production. What types of data are needed to assess the potential, and possibly real, production and economic effects of pollinator deficits? We suggest the following, with comments on the general availability of each type.

1. For each plant and each of its cultivars, the importance of pollination must be assessed in terms of pollination requirements; the nature of the most useful pollinators or assemblages of pollinators; the effects of providing the best possible and most practical pollinator force on seed yields, particularly seed quantity and quality; and the most cost-effective pollination scheme. Although there is some information on pollination requirements (Free 1993, Roubik 1995, Delaplane and Mayer 2000), much of it should be completely re-evaluated because it is dated, anecdotal, and not based on scientific methods. With regard to the most useful pollinators and their effects on seed yields, all too often honeybees are advocated as the only practical pollinators. In addition, assemblages of pollinators provide the most powerful pollination forces for plants of garden, and obviously more research is needed in both these areas. With regard to cost effectiveness, the value of improved plants must be set against the cost of better pollination, and the cost of pollination in terms of the overall cost of producing particular plants is likely to vary widely.
2. The basic information derived from the studies would translate into on-garden economics and financial planning.

3. From that point, the economic ramifications of practices in pollination technology at the garden level could be modeled to include effects on local, regional, national, and international scenario. The estimation of pollinator supply and demand curves is a difficult task because neither is observable. What may be observable is the production of seeds/fruits. This is basically the intersection of the supply and demand curves at the point in time. Multiple observations indicate the location of the intersection of supply and demand equations. Determining the functional form of the two equations and how they have shifted over time is a difficult theoretical and empirical challenge. Nevertheless, techniques are available to accomplish this task. To fully analyze the economic impact of pollinator crisis in garden, it would be necessary to include alternative methods in pollination service of garden plants. However, it is not clear that the information on the incidence and severity of pollinator deficits represent core data for the economic analysis of the impact of pollinator deficits in botanic gardens.

**Conclusion**

We conclude that there is no information to suggest the existence of pollinator crisis that have affected and are affecting successful pollination of plants in botanic gardens. The analysis attempts to illustrate that the full economic impact of pollinator declines cannot be determined by examining only the decrease in production that is caused by pollinator declines. The magnitude of pollinator declines should be determined by empirical analysis on the basis of garden plants' pollination data. Clearly there is a need for pollination ecologists to join forces with economists who share their interests in production and provide more comprehensive analyses of this problem. Such research could yield information that would enable individual garden lovers to integrate pollination into their fiscal and plant–pollinator resource use planning. While the pollination requirements of many plants appear to be small, their marginal impact may be large. An attempt to document the conservation status of pollinators in botanic gardens may reflect the need for further basic research into pollination systems, and into the natural fluctuations in pollinators' abundance. The main impediment to implementing any of the large-scale studies may recommend intensive collecting efforts to produce large numbers of species that require identification. Pollinator identifications and evaluation are often difficult, and the number of insect taxonomists is limited. The abundance and diversity of insects, their role in pollination systems, and their multiplicity of larval roles indicate that insect declines would probably affect multiple levels within botanic garden. The development of checklists for plants and pollinator resources of botanic gardens would be a useful first effort. Resampling in garden community would provide much needed data that would allow us to evaluate the conservation status of the plants. Habitat conservation may ultimately be the most effective tool in conserving plants and their pollinating agents in botanic garden. Current and future studies must adopt a minimum standardization of alternative pollination methods to allow comparisons across the garden, time, and independent studies.

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