CONSERVATION OF POLLINATOR SERVICES IN RAIN FORESTS

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What escapes the eye, however, is a much more insidious kind of extinction: the extinction of ecological interactions.

Daniel Janzen, 1974.

INTRODUCTION

In the current rush to conserve the biological diversity of this planet, most attention is being paid to species inventories with too little attention to the ecological role of these species. This is understandable because of the perception of great threat to natural habitats throughout the world. However, unless there is insight into the contribution of particular taxa to ecosystem function, prioritisation of conservation efforts and even better directed efforts at conservation would be impossible. It is pragmatic to expect that certain taxa will gain more acceptance as conservation targets if they are found to be invaluable to human existence. This is why when conservationists estimate that a bee, butterfly, bat, bird, or other pollinator is responsible for 1/3rd of all foods consumed by humans (Ingram, Nabhan and Buchmann 1996), this should be sufficient cause for strong lobbying for the protection of pollinator services.

Greater than 30 animal genera consisting of hundreds of species pollinate the 100+ crops that feed the world (Prescott-Allen and Prescott-Allen 1990). Only 15% of these crops are serviced by domestic honeybees while 80% are pollinated by wild bees and other wild organisms. Animals provide pollination services for over 75% of all the world's staple crops and for 90% of all the world's flowering plants (Buchmann and Nabhan 1996). Constanza *et al* (1997) estimate that annual services due to pollinators is worth $112 billion. Another independent estimate rates the value of pollination services for global agriculture at $200 billion (Richards 1993). Honeybees are believed to pollinate $10 billion worth of crops in the USA annually (Watanabe 1994) Considering this widespread dependence of wild plants and crops on pollinators, it is therefore natural for concern to be exhibited when these ecosystem services are perturbed. For example, in the USA, the number of commercial bee colonies declined from 5.9 million (1940s) to 4.3 million (1985) to 2.7 million (1995) (USDA Report).

This paper will examine the problem of pollinator declines and will attempt to view the following questions globally and then locally for India: Are pollinator declines a real phenomenon? What causes these declines? What are the consequences of such declines for ecosystem functioning, plant and pollinator genetic heterogeneity, as well as the economics of food and natural resource productivity? If adequate answers to these questions are unavailable, what are the reasons for the gaps in current knowledge? This will not be an exhaustive review but will provide adequate referencing so that these issues can be followed up further.

POLLINATOR DECLINES: ARE THEY A REAL PHENOMENON?

Over the last few decades the perception has been growing among pollination biologists that pollinators have declined in numbers resulting in decreased seed and fruit set in the plants that they service (Buchmann and Nabhan 1996, Allen-Wardell *et al.* 1998). However, a distinction needs to be made between declines of commercially raised pollinators of crop plants and those of natural pollinators. Globally, over 180 species of birds and mammals in 100 genera of vertebrate pollinators are already listed as endangered (Nabhan and Buchmann 1997). In Costa Rica, wild bee species richness in degraded forest lands declined from 70 to 37 species in 14 years (Nabhan and Buchmann 1997).

Despite the alarming trends of declines in fruit set of many commercial crops and naturally-growing plants, it is necessary to examine whether this decline is due to pollinator declines, whether these declines are of natural or commercially introduced pollinators, and therefore whether decreased fruit set can be automatically taken to be a surrogate for declining pollinator populations. There appears to be ample evidence of declines of commercial raised pollinators introduced into agroecosystems for pollination. However, the data are few for natural pollinators. In India commercial honeybees are also suffering serious declines (Sihag 2001). Cox et al (1991) found that overhunting of the megachiropteran fruit bats in the islands of the South Pacific reduced the fruit yields of some traditional harvests. Yet, several long-term studies, particularly of bees, has indicated that there is tremendous natural spatiotemporal unruliness in pollinator numbers (Cane and Tepedino 2001); this natural stochasticity (Roubik 2001, Williams et al 2001) could confound very real trends of pollinator declines. Additionally, the pollinating organisms are also poorly known, which further impedes any examination of population trends. For example, Kearns (2001) believes that although flies are extremely important pollinators, this is not widely appreciated and consequently dipteran populations are not being adequately monitored. A consensus seems to be emerging that although there are definite indications that natural pollinators have declined worldwide, consistent, innovative, and appropriate sampling must be conducted to track these trends.

POLLINATOR DECLINES: CAUSES

Pesticides: Widespread usage of pesticides is a major threat to pollinators worldwide, especially with the onset of modern large-scale agricultural practices. This results in the requirement of large number of commercial bee colonies for pollination. These pollinators feed on the contaminated flowers which has resulted in bee poisoning becoming the most important problem for beekeepers throughout the world (Johansen 1977). Honeybees are susceptible to almost all pesticides used commercially to control pests and diseases (Logan and Schofield 1984). Poisoned bees not only die but, even on exposure to sublethal doses, suffer disruption in dance behaviour and thereby breakdown of accurate communication of information about resources (Schricker and Stephen 1970). Poisoned queens are unable to maintain control over the hive and are often superceded (Chaudhry and Johansen 1971). A major factor contributing to the surface contact action of pesticides on pollinators such as bees is that their branched body hairs, which are adapted for picking up pollen, facilitate enhanced surface loading of insecticides (Pradhan 1949). In India, also, pesticides cause severe mortality of bees (Anita et al.

1993). Although data are not yet available, application of pesticides in tea and coffee plantations in the diverse and ecologically sensitive areas of the Western Ghats can be severely damaging to natural pollinators. The effect of biological pesticides, e.g genetically engineered plants carrying the *Bt*-toxin gene, on pollinators such as butterflies could be serious. For example Bt-corn plants might represent a risk because most hybrids express the Bt-toxin in pollen, and corn pollen is dispersed over at least 60 m by wind Corn pollen deposited on other plants near corn fields can be ingested by the non-target organisms that consume these plants Losey et al. (1999) found that larvae of the monarch butterfly, *Danaus plexippus*, reared on milkweed leaves dusted with pollen from Bt-corn, ate less, grew more slowly and suffered higher mortality than larvae reared on leaves dusted with untransformed corn pollen or on leaves without pollen.

Agricultural practices: Modern agriculture is large-scale, usually monoculture, and often involves removing of surrounding natural vegetation. Monocultures reduce floral diversity, thus limiting the variety of pollinators that could be supported (O'Toole 1993). Extensive cultivation with loss of intervening natural vegetation results in loss of nesting areas for pollinators such as bees, fewer larval host plants for pollinators such as butterflies as well as loss of diversity of microhabitats suitable for egg-laying and early development (Kearns *et al.* 1998). Removal of nectar and pollen-providing "weeds" within expanses of agricultural monocultures by the use of herbicides has major effects on pollinators especially honeybees (King 1961). Agricultural practices that require frequent tilling and irrigation also cause declines in soil nesting bees In India, the soil nesting bees *Andrena ilerda* and *A. laena* that are important pollinators of the oilseeds, *Brassica campestris* and *B. juncea*, showed a six and thirteen-fold declines from 1980 to 1992 (Sihag 1993).

Fragmentation: In order to assess the effect of fragmentation on pollinator populations, it is necessary to know the scale that is relevant to the pollinator (Cane 2001, Borges 2002). For example, a landscape suitable for pollinating bees must contain nesting areas, nectar and pollen sources, that for pollinating butterflies should contain larval and adult food plants, while that for pollinating birds should contain abundant nectar resources. A landscape mosaic that contains these elements in the appropriate configuration that takes the mobility of pollinators into consideration would be able to sustain viable pollinator populations. There are very few data on the effect of fragmentation on pollinator populations, and these mostly pertain to possible effect of fragmentation on nesting attributes of bees (Aizen and Feinsinger 1994, Cane 2001). Powell and Powell (1987) found that males euglossine bees that are important pollinators of Neotropical orchids would not cross cleared areas larger than 100 m, thus indicating that the intervening matrix between forest fragments has a significant effect on pollinator movement and therefore also perhaps on pollinator populations. However, populations of understorey hummingbirds in Amazonia were found to be unaffected by fragmentation (Stouffer and Bierregaard 1995), thus emphasizing the need to investigate fragmentation effects at scales relevant to different taxa.

Parasites: Infections by the parasitic mites *Varroa jacobsoni* and *Acarapsis woodi* have been devastating populations of commercial honeybees (Crane 1988, Ritter 1988). *Varroa*'s original host was the Asian honey bee *Apis cerana* from which it spread to *A. mellifera* when *mellifera* was introduced into Asia for beekeeping (Eickwort 1988).

Problems of chemical resistance and large-scale population declines due to mite infestations have resulted in the general decline of beekeeping (Kearns *et al.* 1998). The Thai sacbrood viral disease in Asian honeybees has also been damaging to commercial pollinations (Reddy *et al.* 1993, but see Rajagopal *et al.* 1998).

Non-native pollinators: The accidental release and now relentless spread of Africanized honeybees into the Americas is regarded as a major threat to commercial honeybees. Africanized honeybees are hybrids between European bees and the African subspecies *A. mellifera scutellata* (Rinderer 1988). Their aggressive nature, tendency to swarm when colonies are relatively small resulting in low honey production, hybridization with local honeybees resulting in transmission of the aggressive phenotype, and tendency to abandon areas under unfavourable environmental conditions makes them unsuitable for apiculture (Kearns *et al.* 1998). Analogous problems have been created by the bumblebee *Bombus terrestris* that was introduced into Japan to buzz-pollinate greenhouse tomatoes. Buzz-pollination is release of pollen from anthers by sonic waves produced by wing and thoracic muscle vibrations. This is necessary particularly in some families such as the Solanaceae whose flowers can only be serviced by pollinators who can effect these vibrations. Prior to the commercial use of bumblebees, hand-held vibrators were needed to effect pollination. The greenhouse bumblebees escaped and now are in competition with the native *Bombus*, as they usurp hives of the native bumblebees by killing the queens. *B. terrestris* is also causing problems in Israel, as it is in direct competition with the native bees in this region also (Dafni and Schmida 1996). Commercial honeybees when introduced into areas for crop pollination can also affect pollinator services provided by native pollinators. For example, various studies have recorded honeybees competing with pollinating birds, buprestid beetles, native meliponid and megachilid bees, with some megachilid bees even showing increased brood parasitism and reduced brood cell production in the presence of the honeybee (Kearns *et al* 1998)

POLLINATOR DECLINES: CONSEQUENCES FOR POLLINATOR SERVICES

Plant population size, density and spatial isolation have complex interactions which can affect pollinator behaviour and thereby pollination (Kearns *et al*. 1998, Borges 2000, Somanathan and Borges 2000) above and beyond effects of plant floral display, pollinator reward structure, and plant breeding system, which have significant effects on pollinator behaviour even in unfragmented landscapes (Waser 1983, Chittka and Thomson 2001).

Biological consequences: The reproductive output of plants in terms of fruit and seeds per fruit is determined by access to resources such as nutrients and water, as well as access to appropriate mates in the form of pollen. Access to appropriate mates is particularly important for plants that are obligately self-incompatible, and for those that occur in small populations and are subject to the negative effects of inbreeding and genetic drift (Saccheri *et al*. 1998, Packer and Owen 2001) In a study comprising 258 plant species, Burd (1994) found evidence of pollen limitation in 62% of the species, thus indicating that plants appear to be receiving less numbers of pollen than they can use for development into seeds As mentioned earlier, although data on pollinator numbers are few, there are many studies that indicate pollination deficits (Kearns *et al* 1998). The fundamental issue is, therefore, whether pollination deficits can be used as an effective surrogate for pollinator deficits in natural ecosystems (Thomson 2001). In agrecosystems, declining fruit or crop yield can often be directly linked to the lack of pollinator services. For example, application of the organophosphorous pesticide Fenitrothion caused severe decline of pollinators resulting in an annual harvest loss of 0.75 million kg of the blueberry crop in New Brunswick, Canada (Kevan and Phillips 2001). In this area, commercial production of blueberries depends on the pollination services of as many as 70 species of native insects (Kevan 1975). Another pesticide induced decline occurred in almond and honey production in California (Siebert 1980) which had to be ameliorated by the import of honeybees from Florida (Watanabe 1994).

Although several pollinators are generalists and visit several plant species, and although many plant species also receive services from a variety of pollinators, these services could be of differing quality. Thus certain pollinators cause enhanced fruit set in both natural and crop systems compared to others (Kumar and Gupta 1993). Some plant-pollinator systems, however, are obligate in that only one single pollinator services a single plant species. In such situations, loss of the pollinator would result in extinction of the plant (Washitani 1996, Borges 2000). If such plants are also keystone species, e.g. *Ficus*, then their extinction could result in cascading effects through communities of frugivores and other taxa dependent on the plants (Terborgh 1986). Some pollinators that are not exclusive to certain plants but service a variety of taxa could, if highly mobile, serve as important mobile links that connect plant communities, e.g. migratory butterfly pollinators and bats (Gilbert 1980).

Economic consequences: Various attempts have been made to evaluate the economic consequences of pollinator services and thereby of pollinator declines. For example, the economic value of a single wild bee serving as a pollinator of blueberry (*Vaccinium ashei*) was estimated at $20/- (Cane 1996). Kevan (1997) found that providing one hive of honeybees per hectare of apple orchards caused an increase in returns equivalent to 700% of the cost of pollination services. The value to US crop yields of pollinators other than honeybees may be as high as $6.7 billion per annum (Nabhan and Buchmann 1997).

POLLINATOR DECLINES: KNOWLEDGE GAPS AND AMELIORATION

Adequate sampling of pollinator populations: Whether the spatiotemporal stochasticity of insect pollinator populations alluded to earlier is a real phenomenon or whether natural populations of pollinators are actually showing a declining trend can only be determined by consistent monitoring (Roubik 2001). Although large scale destructive sampling for insects, e.g. using light traps, may have been acceptable in the past, they are unacceptable today, since the sampling protocols themselves may deplete already endangered pollinator populations. Hence, non-destructive protocols need to be evolved, not just for insects, but for the entire set of invertebrate and vertebrate pollinators. In many cases, as mentioned earlier for flies, the importance of particular taxa as pollinators is completely unknown. Hence data need to be collected on pollinator services and on pollinator populations. Although evaluation of pollinator services for individual plant species requires experiments that consist of comparing fruit set in the presence and absence of the pollinator, even a record of visitors to the flowers of different species could help at a preliminary level to determine pollinator importance. Identification of important pollinators or guilds of pollinators can then serve to prioritise conservation efforts.

Effects of pesticides and appropriate laboratory trials: Although the toxic effects of pesticides on many commercial pollinators, e.g. honeybees, is known, their effects on wild pollinators is largely unrecorded. Since many pesticides are picked up on the body surface and surface to volume ratios are involved, smaller bees may be more susceptible than larger bees; however more research is needed. Considerable research is required on a) natural control methods and pesticides that are not lethal to pollinators, and b) protocols of pesticide application that minimize exposure and thereby lethal effects on pollinators. For example, pesticide application could be scheduled either when pollinators are least active during the day, or before and after flowering. Data are needed on crop yields using natural control methods. For example, some studies indicate that organic farming that encourages and maintains natural habitat, which in turn sustains natural populations of pest predators, is as economically viable compared to farming with pesticides (Batra 1981). More data are needed on this issue. In the current globalisation scenario, unless consumers are convinced of overall benefits to human and ecosystem health of consuming products free of pesticides, and unless organic farming is shown to be as economically viable as that using pesticides when all externalities such as pesticide induced death and/or disease are factored in, there is always the danger that producers that use pesticides will be able to dictate prices (Kevan 2001).

Pollinator behaviour and ecology: Knowledge of pollinators is heavily biased toward bees, and that too heavily towards the Neotropical, North American and European fauna. For examples, a major treatise on tropical bees (Roubik 1989) cites 1400 references but only 89 of these refer specifically to south and southeast Asia. Pollinators such as butterflies, beetles, flies, thrips, birds and mammals have been severely neglected.

Commercial honeybees alone, even if bred intensively, cannot provide pollinator services in all ecosystems. As has been seen, even in most agroecosystems, the contribution to pollinator services by native pollinators is significant. Therefore data on natural pollinator ecology, especially feeding and breeding biology is vital to maintain the integrity of both natural and agroecosystems, as is an understanding of the complexity of the mutualisms involved.

Better economic evaluations: From a pragmatic perspective, the more knowledge we have about the economic value of pollinators and their costs of replacement, the more convinced will the general public be about the value of pollinators. It is apparent that the pollinator crisis in the USA especially in agroecosystems has become sufficiently alarming for the US Secretary of the Interior, Bruce Babbitt, to say the following in a public speech in 1998: "Pollinators: These hardworking heroes of nature are not well understood but clearly in peril. Loss of habitat, poisonings, and fragmentation of plant life on which they depend is reducing the number of pollinators alarmingly". Jamie Rappoport Clark in a 1999 memo to all US Fish and Wildlife Service biologists said: "I am convinced that restoring and conserving pollinators will be one of the most pressing challenges to maintaining biodiversity and healthy ecosystems in the coming decades." It is only if the pollinator crisis can be seen to have a direct current or future impact on the economy or on public perceptions of planetary health, will politicians be forced to institute policy to meet the demands of this crisis effectively. Scientists and economists must work together urgently towards this end.

Looking into the future of pollination services in India

The pollinators of the Indian flora are very poorly studied, except for some economically valuable plants, e.g. cardamom. Visitors and thereby putative pollinators of the natural shrub and tree flora have been recorded for only a few Indian forests, e.g. evergreen rain forest in Kakachi (Devy 1998), semi-evergreen crest forest in Bhimashankar (Somanathan and Borges 2000, Somanathan and Borges 2001), and a mangrove forest along the eastern coast (Pandit and Choudhury 2001). The vast remainder of sites and plants remain unstudied and do not feature in a pollination data base. This scenario must change if practical conservation measures and effective protection to pollinators and plants is to be effected. Although there is extensive commercial exploitation of fruit crops of forest trees such as *Garcinia gummi-gutta* and *Myristica* spp, there is no knowledge of the pollination of these species which is an upstream process that must be necessarily conserved to ensure continued fruit production on existing trees. The trend of conversion of coffee plantations to tea gardens following the fall in coffee prices could have very serious consequences for the natural pollinator fauna of Indian forests. This is because most shade coffee plantations retain original old-growth shade-trees. Removal and replacement of such trees by exotics such as *Grevillea robusta*, as occurs in tea gardens, would impact on pollinator fauna many of whom could be using these tree species for larval and adult food resources, mating and nesting spaces and other purposes. Furthermore, considering that most of the southern Indian hills are largely a mosaic of tea and coffee plantations, with natural forest fragments occupying a very small area of this composite matrix, the seriousness of land use changes cannot be ignored. Despite the alarming trends world-wide about the effect of crop pesticides on native and commercial pollinators, the agricultural sector in India is still heavily dependent on pesticides that are harmful to pollinators such as honeybees (e.g. Reddy and Reddy 2002). Although there is a requirement of 150 million honeybee colonies in India for the successful pollination of commercial crops, there was only 0.004 percent of this requirement in 1982 after which the numbers declined still further due to disease (Sihag 2001). The "All India Coordinated Project on Honeybee Research and Training", set up by the Indian Council of Agricultural Research to facilitate cross-pollination of crops plants and honey production, has largely been a failure (Sihag 2001). The genuine shortage of competent systematists to identify pollinator taxa is also a major constraint in the conservation and study of species interactions. Policy makers must pay serious attentions to this shortages and must encourage the growth of scientific systematics and pollinator conservation in the country.

Pollinator services are complex, and with as yet unknown properties of resilience or sensitivity to perturbations. It is very likely that the pace of habitat degradation will proceed at a faster rate than our understanding of this complexity. In this scenario of only slowly diminishing ignorance (Borges 2002), the best strategy would perhaps be to devise pragmatic, low-risk strategies for the maintenance of pollinator diversity. Such pragmatic strategies might involve the assiduous protection of the maximum number of refugia containing natural vegetation whether this occur around the edges of agricultural lands, forest islands within a sea of plantations or other such matrix. Such preservative strategies coupled with active interaction of policy makers, economists and biologists appears be the only method for the successful maintenance of pollinator diversity.

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