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Review

Pollination: A threatened vital biodiversity service to humans and the environment

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Pollination is one major biodiversity service that cannot be adequately quantified economically yet the variety of approaches nature has engaged to accomplish it is hardly appreciated. In this review, the types and agents of pollination, faunal and floral architectural and behavioural adaptations and special rare cases of pollination syndromes are highlighted. Anthropogenic roles that have resulted of threats to pollination and pollinators were identified as habitat fragmentation and loss, deforestation, desertification, industrial and infrastructural development. These eventually impinge on the unique ecological and economic services that pollination renders to sustain life on planet earth.

Key words: Pollination, biodiversity, floral architecture, faunal behaviour.

INTRODUCTION

Whether in terrestrial or aquatic environments, pollination and pollinators render vital ecological and economic services in the sustenance of life on planet earth. For instance, crops rely on pollination to turn out the food on which humans and other animals depend for survival (NWF, 2001), whereas pollinators themselves provide this service in a quest to find their own food. In addition, the activities of pollinators - those busy, often-unacknowledged creatures - vitally maintain the healthy reproductive cycle of organisms at the ecosystem, species and genic levels of biodiversity. How, if we may ask, could we possibly get a product as unique as "honey" if honeybees or other types of bees stopped searching for nectar from flowers? Conversely, how would plants, which produce the all-important nectar processed into honey, effectively be pollinated for perpetuation if there were no particular types of bees that visit particular plants in bloom for nectar or pollen thievery? Would the world enjoy food security if pollination is eliminated from nature? How much in monetary terms can humans possibly pay for such service even if such costs were estimable, and to whom would we pay? The obvious answers to these questions highlight, *a posteriori,* the invaluable service the process of pollination is to the survival of not only the plants, but also their pollinators, and by extension to humans - the ultimate beneficiaries of biodiversity goods and services.

Biodiversity is a compound word from "biological diversity" coined by Edward Wilson in 1986 to describe the diversity of life forms observed in plants, animals and micro organisms; and how these interact to maintain life on planet earth at the levels of the gene, species and ecosystems. Obviously life on this planet is inconceivable without the goods and services rendered by all components of biodiversity. Apart from human dependence on biodiversity for such direct functions like purifying the air the, land and sea, there are those essential biodiversity services to humans that drive the phenomenon called "life". For example, green plants through photosynthesis trap and convert solar energy into chemical energy to provide the food, clothing, medicinal and fuel needs of animals and humans. In order to ensure that this cyclic programme of interdependence continues, pollination provides the renewal link from one generation of plants to the next especially for those plants that reproduce by sexual means. This does not in any way exclude the role played by those plants that reproduce by asexual means only.

Our focus in this essay is to highlight the process of pollination, its significance, forms and pollination-related structural, chemical, behavioural and other adaptations by different plants and animals to mutually serve the needs of each other and humans for survival.

DEFINITION

Pollination is defined as the transfer of pollen grains from the anther (male sex structure) to the stigma (female sex structure) in flowers of angiosperms, or from the micro-sporangium to the megasporangium in gymnosperms directly or usually through an agent or portal. The mediating agents include wind, gravity, water and animals. In some cases, the transfer is completed via strictures imposed by the architectural design of the flower, which allow for completion of the pollen grain transfer to the stigma before the flower opens up. This effectively occludes activities of "visitors" to the flower and thus it (the flower) self-pollinates. Suites of circumstances, known as pollination syndromes, make for success in each pollination event as a result of natural selection and co-evolution of plants and their pollinators. These syndromes are either mutualistic or antagonistic traits shared by plants and their pollinating agents for successful pollination for the plant on one hand, and for nectar or pollen grain thievery for the pollinator on the other.

The "classical" pollination syndromes were advanced by the Italian botanist Federico Delpino in the 19th Century. Generally, the syndromes may be categorised into biotic or abiotic pollination syndromes. Abiotic syndromes are recognised thus:

- Wind pollination syndromes: termed anemophily whereby pollen grains are carried by wind to the receptive stigma of the same plant, related species or another unrelated plant.
- Water pollination syndromes: called hydrophily involving the transfer of pollen grains from anthers to stigmata through the agency of water.

The following categories are recognized for the biotic syndromes.

(a) Insect-mediated syndromes: are generically termed entomophily but may further be classified according to the specific insect groups as:

- Bee pollination syndrome called melitophily
- Butterfly pollination syndrome referred to as psychophily
- Moth pollination syndromes called phalaenophily
- Fly pollination syndrome or myophily, sapromyophily based on the type of fly.
- Beetle pollination syndrome or cantharophily

(b) Bird pollination syndrome or ornithophily.
(c) Bat pollination syndrome or chiropterophily.
(d) Snail-slug pollination syndromes otherwise termed malachophily.

Broadly, there are two types of pollination events according to the extent of involvement of external factors. These are:

- Self-pollination with no contact with any external agent;
- Cross-pollination that is pollen grains are only receptive to the stigma of another of its kind but not receptive to its own stigma.

While self-pollination is simply the phenomenon of pollen grain transfer from the anther to the stigma of the same flower without the mediation of a portal or agent, several variants of cross-pollination exist. One variant of cross-pollination technically termed allogamy is where two related plants with different genetic backgrounds are involved in pollen grain transfer and stigmata reception. The second type identified as autogamy is that where pollen grains from a flower are transferred to the stigma of the same flower but with the mediation of an agent. Further still, another cross-pollination variant exists where pollen grains get to the stigma of a similar flower borne on another related plant. This is called geitonogamy. Extreme or obligate cases exist when pollination can only take place between the anther and stigma of two flowers borne on separate plants, called xenogamy.

Over the years, plants have evolved peculiar strategies to ensure that come what may, pollen material is deposited on the stigma of relevant flowers in an ordered manner so that plant life is perpetuated.

THE ECONOMICS OF POLLINATION

Manifestly, the services rendered by pollinators translate to incalculable economic and ecological benefits not only to the flowering plants, but also to humans, wildlife and ecosystems generally. That is, if we consider the colossal amounts of pollination events that go on globally. Pollination, therefore, is one of, if not the most vital service of biodiversity, which not only ensures continuity of life for green plants but also plays a pivotal role in the provision of food, habitat and other life-sustaining functions for all organisms.

In view of the spatio-temporal imperatives of perpetuating life, an individual or group of individuals must replenish their stock from one generation to another if they must survive life's vicissitudes. Animals generally have developed sex selection and mating rituals to address this need. In response to problems associated with plant reproduction in the terrestrial environment, seed plants developed flowers (florigenesis) from their vegetative parts. Vegetative shoots became modified to form structures adapted for formation of new individuals within an enclosed moist environment. This came in a wide spectrum of simple to quite complex architectural modifications of flowers seen in different angiosperm families; each specifically designed to capture the array of niches that meet the plant-pollinator interactive needs. The extent of complexity encountered to achieve this will never be fully quantified in economic terms even if humans can try.

Different flowers and their animal pollinators shall be

Figure 1A. Solitary flower of Clappertonia ficifolia representing the typical flower – a structure designed to ensure perpetuity of terrestial plants. Notice the red colour style bearing the stigma and the yellow colour anthers enclosing the pollen grains. The style sticks out so that pollinators brush against it during visits either into or out from the flower in search of nectar (Source: Gordian Obute).

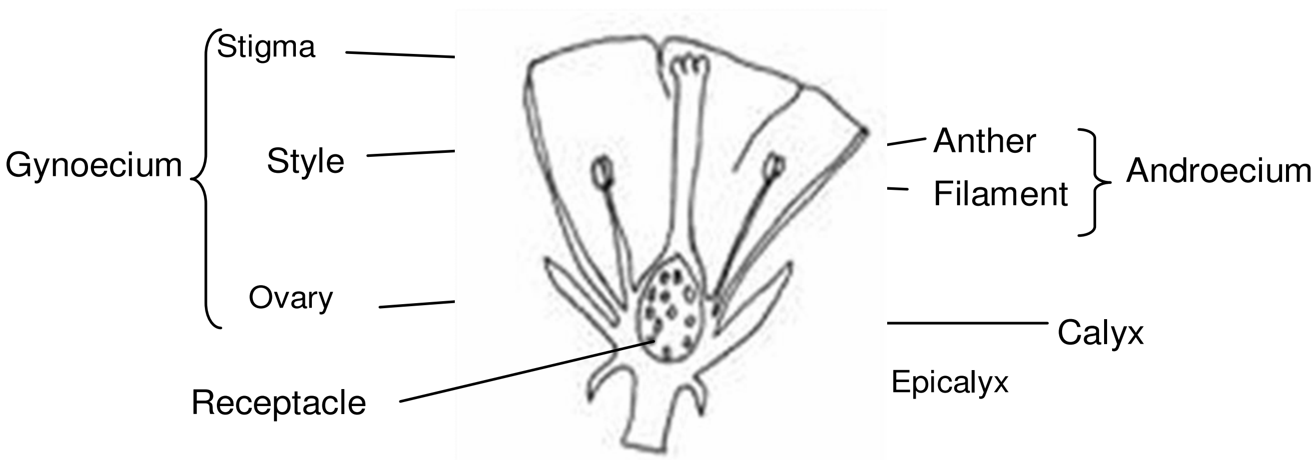

Figure 1b. The parts of a typical angiosperm half-flower.

highlighted in this essay, with respect to floral-cum-faunal structural modifications and the dynamics of spatio-temporal behavioural strategies between relevant fauna and flora, to ensure pollination.

Essential structure - the flower

The flower is essentially a vegetative shoot that infolded to protect the delicate ovule that eventually forms the next generation of flowering plants. In other words, the calyx, corolla, androecium and gynoecium are really leaf modifications to ensure that a structure for regeneration is formed by seed plants. Further modifications around these generic parts resulted in the vista of structural differences that aided the success of angiosperms over other plant groups. A generalised or typical flower is shown in Figure 1a while Figure 1b shows the same flower cut in half with some parts removed, to reveal the juxtaposition of the essential floral parts - the anthers and stigma.

A diagrammatic representation of a typical flower (Figure

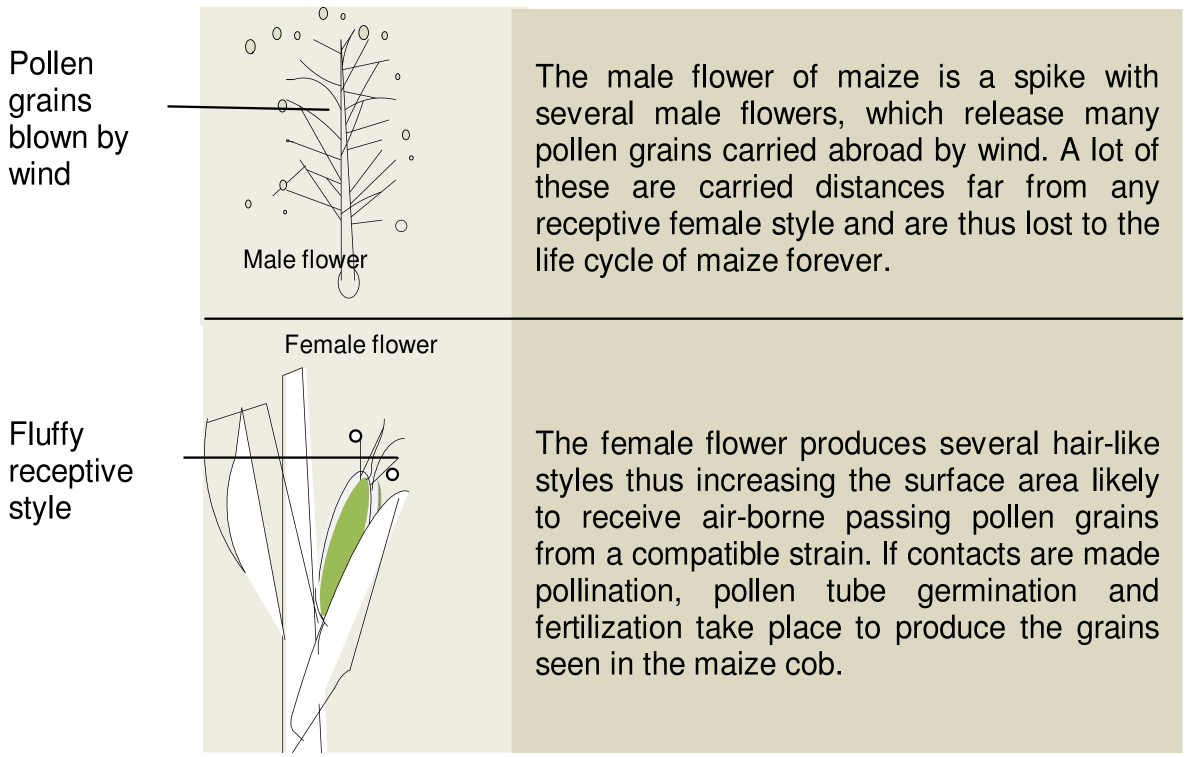

Figure 2. Wind pollination in *Z. mays* showing possible wastage of pollen resources and the strategy of producing several styles to ensure that several ovules are pollinated.

1b) however, indicates that the pollination process does not involve the gymnoecium and androecium alone but also every part of the flower since each plays a role during pollination.

For instance, the colour of the petal, just like green colour in leaves, is perceived by some particular pollinators and these will definitely visit flowers in bloom. Some petals also are designed with lines called nectar guidelines which aid the pollinators to navigate to the nectarines.

WHY ARE PLANTS POLLINATED?

Agents of pollination usually seek substances in the flowers for food while inadvertently pollinating the flowers in the process. Buchmann and Nabhan (1997) recorded that pollination by insects is the first step in the fertilization and fruiting process leading to the production of vegetables and fruits. Viable seeds produced by the process provide 35% of the human diet. Michener (2000) remarked that bees with about 17,000 known species are the world's dominant pollinators; whereas Buchmann and Ascher (2005) affirm that bee species collectively pollinate the 250,000 known angiosperm species.

Natural selection pressures for pollinator/plant combinations are often tilted towards cost effective energy budgets to avoid profligacy in pollen production and utilization; and at last yield mutual benefits to plants and pollinators alike. For instance, most animal pollinated flowers produce less pollen grain in comparison to wind and water pollinated ones. A complex of circumstances also work to the advantage of the pollinator in that most of them visit only specific flowers and conserve the energy expended in search of food. Conversely, wind-pollinated flowers waste so much resources by producing copious amounts of pollen grains most of which are blown away without effectively pollinating any flower; yet enough pollen would still land on target to ensure pollination. An example is seen with pollination in maize, *Z. mays* (Figure 2) which brings into focus the amount of wastage of resources to ensure perpetuity. Plants are, therefore, pollinated to ensure continuity of sexually reproducing species while sustaining and maintaining life for the pollinator; in addition pollination of plants is vital to ecological stability and provision of invaluable services to humans.

Floral-faunal architectural structures

When insects started to feed on the sugary substance produced by plants, the need to protect the structures producing the sugars arose as collateral. The most successful coping strategy for plants was for special leaves to be developed to wrap around these delicate

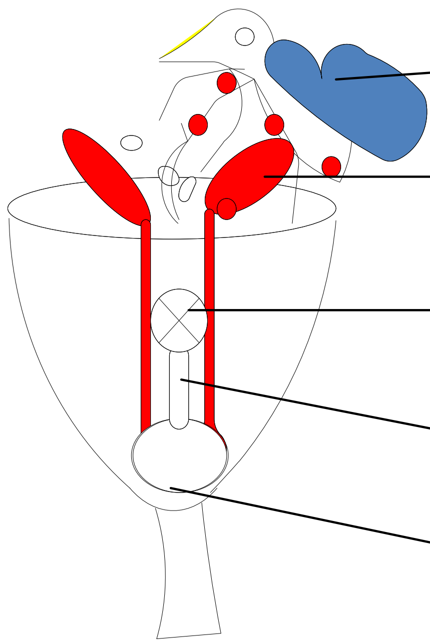

Figure 3a. Stylized diagram of an aspect of insect pollination syndrome.

Figure 3b. Honey bee visiting a flower (Source: David Crossley, 2006).

parts. This point, according to most evolutionary biologists, marked the beginning of covered ovules that led to formation of the group of plants called angiosperms. This factor resulted in the co-evolution between flowers and pollinators making for the mutualism observed in animal pollinated plants (which by the way are more successful than wind pollinated ones). This stylized diagram (Figures 3a and b) depicts co-evolution of mutual traits between flower and insect pollinator.

Notice the short style and protruding stamen as well as the nectary at the base. The pollinator must first encounter the pollen grains, then the stigma before reaching

Figure 4. Self pollination in *Mucuna slonei*.

reaching the nectaries for thieving. In all cases of pollination, the physical structures of either the flower or/and animal pollinator play significant roles to ensure success. Literature is replete with evidence that the shape of flower and the mouthparts of the animals usually co-evolve in a highly mutualistic manner to render a high level of species specificity for pollinators and the plants they pollinate. Carter (1999) stated: “Co evolution is the mutual evolutionary influence between two species (the evolution of two species totally dependent on each other). Each of the species involved exerts selective pressure on the other, so they evolve together…” With respect to pollination, pollinators and floral structures, this co-evolutionary phenomenon is seen for instance, where the pollinator’s mouthparts or body length is the exact size of the flower it pollinates. Carter reported, for instance, that Charles Darwin observed the size and shape of a possibly moth-pollinated flower he saw in Madagascar and predicted that a moth would exist that specifically pollinate that flower. Not surprisingly, such a moth for that particular flower was discovered 40 years later.

The few illustrations below depict some structural adaptations of pollinators and flowers for each category of pollinator / pollination syndrome.

The individual flowers are positioned in a way that foraging bees easily alight and walk over the anthers while probing for the nectar. After the reward, the bee takes off and moves on to alight on another flower; but then it carries pollen grains picked from the previously visited flower on its body. As it alights, the structure of the flower is such that some of the pollen load will be shed on the newly visited flower thus bringing about pollination.

Mucuna slonei floral parts (tepals) are wrapped up throughout the process of anthesis (bloom) so that when the flowers open at the tips eventually, pollination would have taken place already. However, some foraging ants and small beetles may still affect minute % of pollination after this opening to ensure an amount of cross-pollination, which improves the genetic integrity of the species (Obute and Ugborogho, 1998). This type of pollination is seen mostly in legumes (Figure 4).

The Monarch butterfly has a long proboscis with which it rummages for nectar. This plant in the family Asteraceae is structurally deigned to provide several disc florets to satisfy the needs of the butterfly. By picking up a pollen burden from this plant, the butterfly takes off to land on another flower of the same plant type. Before reaching the nectaries, much of the pollen load on its proboscis is shed on the stigmatic surface of the new plant to inadvertently effect pollination (Figure 5).

Dull coloured flowers are pollinated by beetles as seen in Figure 6a. By crawling over the flowers, pollen grains are picked and may be dropped on the stigma of another compatible flower. The beetle usually goes for pollen thievery and as such plays its role in the cycle of life.

The "petals" of members of the Asteraceae family are designed as guides called "ray flowers". These modified flowers are large and bent back to draw attention to the centre of the flower, where the fertile "disk flowers" are

Figure 5. Butterfly on a flower head (Source: Google images, 2008).

Figure 6a. Pollination by beetles is common in drab-coloured flowers (

located (Figure 6b). Flies crawling over the disc florets pick up and spread the pollen grains to other plants of the same type to effect pollination when they alight and crawl on them.

Moths, like butterflies, alight on flowers structurally designed for landing. The flowers usually provide a white background (Figure 7) since moths can only distinguish such at dusk when they move about for food. The hairy body

Figure 6b. Flies also play roles in pollination of compound flowers (Source: Google images, 2008).

Figure 7. Moths are adapted to pollinate white flowers since these open late evenings (Source: Google images, 2008).

of the moth and the sticky nature of the pollen grains combine to ensure that a heavy pollen burden is on the moth while this ensures that the next landing on a similar flower will result in pollination.

The Yucca plant has flowers that are not open to any other set of pollinators but moths. These insect lays its egg inside the Yucca flower (Figure 8). In essence, the act of getting a “nest” for its offspring ends up pollinating

Figure 8. Flowers of Yucca plant are adapted for moth pollination by shape and colour (Source: Google images, 2008).

Figure 9. Humming bird seeking nectar in *Fuchsia* pendulous flowers with stamen touching the head to carry pollen grains to deposit elsewhere.

its host flower.

Humming birds pollinate huge pendulous flowers because their hovering around the mouth of the flower (Figure 9) leads to pollen material falling on the heads. The beak is designed to probe into the depths of the flower for nectar. A visit to another flower of this type will ultimately result in some of the pollen shed on the stigma thus effecting pollination.

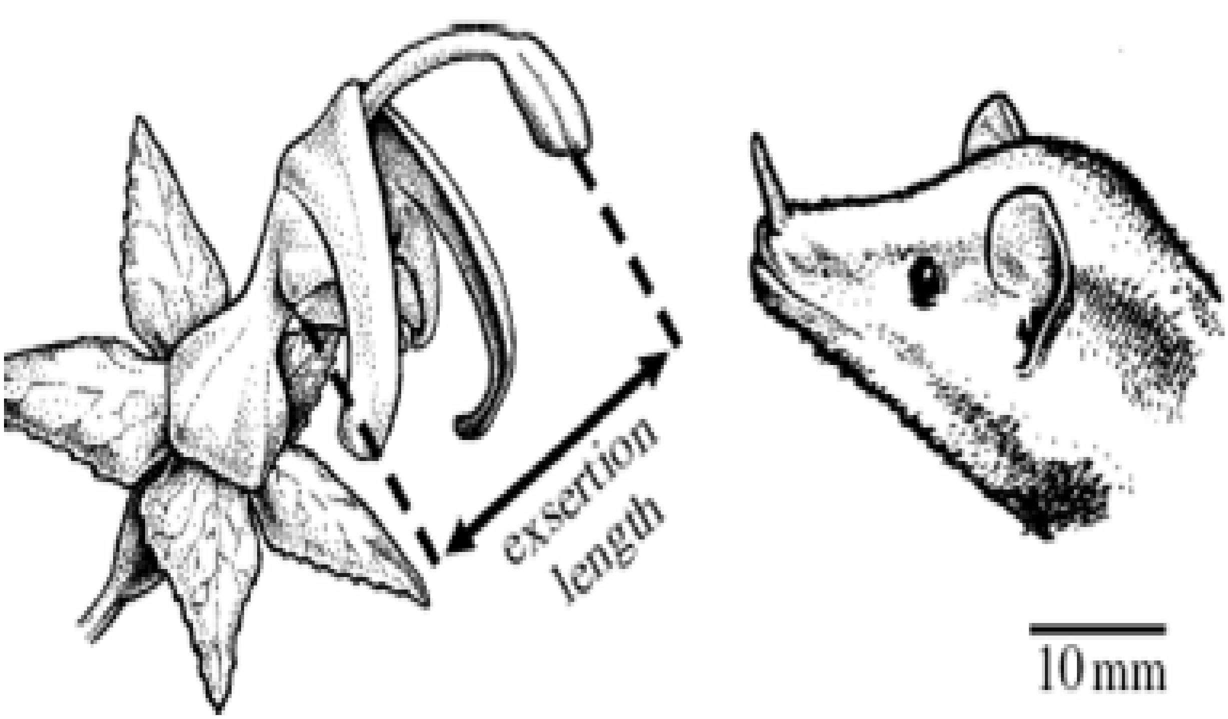

Figure 10. Flower of *B. borjensis* showing the exsertion length and the head of its co-evolved pollinator the nectar bat *Anoura geoffroyi* of Ecuadorian forests. Modified from Muchhala (2006).

Bats pollinate flowers of species of genus *Burmeistera* (Muchhala, 2006 indiscriminately thus leading to competition for pollinators in these sympatric species. Some members developed structural differences in flowers within the genus to allow particular bats to visit and eventually pollinate them. In a typical case *B. borjensis* flower and the exsertion length, that is the distance from the constriction of the corolla tube to the distal portion of the staminal column can accommodate the head of bat *Anoura geoffroyi* (Figure 10).

MOST UNHEARD OF POLLINATORS

Snails and slugs are herbivores that feed on soft vegetation and are most unlikely to be considered as pollinators. Some flowers, however, would not attract flying pollinators because they are so close to the ground and are covered by leaf litter. It is believed that slugs or snails may pollinate these flowers (i.e. wild ginger). Recent studies have revealed that gastropods also partake in the pollination phenomenon. Sarma et al. (2007) demonstrated that snails are not as destructive as had been thought but rather are engaged in the service of pollination of some plants. Still in response to challenges of the environment, snails, researchers report, have co-evolved with some members of the Convovulaceae family that is the morning glory group as their specific pollinators. Atimes these prostrate plants climb on other plants and are visited by honeybees especially during warm days. In order to keep up with high fecundity in the group they resort to pollination by snails as well during wet seasons. Figure 11 shows one such visit of snail to the plant *V. nummularium*. The type of pollination in this case is malacophily.

FAUNAL-FLORAL SPATIO-TEMPORAL BEHAVIOURAL STRATEGIES

The reproductive behaviour of living organisms is a complex interaction of age, response to intricate chemical stimuli and environmental set ups. Animals are attracted to flowers by the colour or odour given off by the flowers at certain periods of their life cycles. Firstly, the attraction is for food or mate (in case of floral mimicry of the opposite sex of the animal) or some sort of reward or thievery (for nectar or pollen) for the pollinator. Secondly, the plant or flower precisely advertises itself with some attractant including odour, colour, shape and texture to which its preferred pollinator responds to more than others do. Another variant of this is the presence of structures that make for effective transfer of pollen material to next flower by the pollinator. Thirdly, the pollinator must establish a pattern of repeated visits to the flower on a regular basis to try to perform the vital transfer apparently dictated by the structure and function of the flower. Carter (1999) reported that irrespective of

Figure 11. The Graceful Awlsnail (*Lamellaxis gracile)* foraging in the flowers of *V. nummularium*. The shell would pick some pollen grains, which are deposited on the stigma of the flower visited.

the complex of behavioural strategies, bees do not recognize red colour; thus, flowers pollinated by this group of animals are usually not red in colour but mostly pollinate those are yellow or blue with UV (ultra violet) nectar guides and specifically designed landing platforms that guide the bee to the nectaries. These UV nectar guides are usually invisible to humans but clearly so to these bees. Apart from this feature, bee-pollinated flowers are also delicate in texture, sweet scented, and are small. In addition, they possess narrow floral tubes, which are perfect-fits for the tongue-lengths of particular species of bee.

THE ORCHIDS

These usually epiphytic plants are represented in tropical and temperate environments and produce specialized and spectacular floral architectural designs to ensure pollination. This is observed in the type of pollen material produced called pollinium and special features of floral structure In a particular case, the Pink Lady's slipper orchid, *Cypripedium acaule* has developed a labellum, which is the upper medial petal, that serves as a trap to hold the insect visitor and force it to pass and brush the anthers during escape thus picking up pollinia, which will be dropped on another flower of the same type it would visit next (Figure 12). Pollinia are the products of only one anther transferred as a single unit during pollination unlike the independent pollen grains transferred as separate units in other plant groups. Furthermore, the receptivity time lapse for the style of some orchids is generally extended to accommodate the inefficiencies of floral architecture determined pollination syndromes.

The Fly orchid (*Ophrys insectifera*) on its own produces flowers that resemble the female of its pollinating agents – flies and bees. However, these flies and bees rarely visit so that the plant forms seeds infrequently. Apart from the shape, Borg-Karlson et al. (1993) reported that the plant uses scent, which mimic the female fly's sexual pheromones to attract male. In a frustrating attempt to mate with this "false" female, the male flies pollinate the flowers.

PHYLOGENETIC ROLE IN POLLINATOR SPECIFICITY

Pollination biology studies have shown that related species adapt different means of achieving pollination even if they are sympatric (occupy same geographic zone). Varassin et al. (2001) studied the role of pigment, nectar production and odour in attracting pollinators to four species of *Passiflora*. Their results showed that *P. alata* was pollinated by bees, *P. speciosa* by hummingbirds

(a) (b)

Figure 12. Orchid flowers. **A.** The Pink lady's slipper orchid, *Cypripedium acaule* displaying the enlarged labellum, which traps insect visitors; in a bid to escape these insects brush n anthers and pick up pollinia to pollinate other plants. **B.** The deceived male fly apparently mating with the flower of Fly orchid, *Ophrys insectifera*; several such matings end in transfer of pollinia from one flower to the other.

hummingbirds, and *P. galbana* and *P. mucronata* by bats. In other words, part of the process of speciation in this group was adapting different strategies for survival and delineation including production of either nectar, chemicals that attract animals with high olfactory sensitivity as well as flower pigment for related species. If we could get these pollination syndromes in one genus, then the diversity and combinations of these syndromes in plant groups and families can only be imagined.

POLLINATORS AND POLLINATION UNDER THREAT

Recent observations resulting from anthropogenic activities show that overexploitation of natural resources (logging, hunting and non timber forest products), habitat fragmentation and loss, deforestation, desertification, industrial development and distortion in predator /prey population dynamics are threatening survival of plants and their pollinators. Logically pollination as a biodiversity service is also under threat. The extension of this threat to other animals and eventually to humans who's very survival depend on these vital services, goods and functions of biodiversity is anybody's guess.

Conclusion

Pollination is rather a vital process significant in the maintenance/sustenance of life on planet earth. As an essential biodiversity service it involves plant and animal species which derive mutual benefits and in turn provide unique services and functions to humans. Its scope, ecological and economic values are inestimable yet human activities are depleting the numbers, habitats, mates and spread of this silent, often unacknowledged but important aspect of biodiversity.

REFERENCES

Buchmann SL , Nabhan GP (1997). The Forgotten Pollinators. Island Press, Washington DC, USA.

Buchmann SL , Ascher JS (2005). The Plight of Pollinating Bees. Bee World, 86: 71-74.

Carter JS (1999). Coevolution and Pollination. www.ailto:carterjs @uc.edu?subject=Coevolution and Pollination Web

Michener CD (2000). The Bees of the world. The Johns Hopkins University Press, Baltimore, USA and London, UK.

Muchhala N (2006). The pollination biology of *Burmeistera* (Campanulaceae): specialization and syndromes. Am. J. Bot., 93: 1081–1089.

National Wildlife Federation NWF (2001). Pollinators' Journey. USA.

Obute GC, Ugborogho (1998). Breeding Systems and Associated Mechanisms in *Vigna unguiculata* (L.) Walpers (Phaseoleae-Fabaceae. Revue de Cytologie et de Biologie vegetales Le Botaniste. 21(3/4): 31 – 38.

Sarma K, Tandon R, Shivanna KR, Mohan Ram HY (2007). Snail-pollination in *Volvulopsis nummularium*. Curr. Sci., 93(6): 826- 831.

Varassin IG, Trigo JR, Sazima M (2001). The role of nectar production, flower pigments and odour in the pollination of four species of *Passiflora* (Passifloraceae) in south-eastern Brazil. Bot. J. of the Lin. Soc., 136(2): 139-152.