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Report

Benefits of Biotic Pollination for Non-Timber Forest Products and Cultivated Plants

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Abstract

Biodiversity supplies multiple goods and services to society and is critical for the support of livelihoods across the globe. Many indigenous people depend upon non-timber forest products (NTFP) and crops for a range of goods including food, medicine, fibre and construction materials. However, the dependency of these products on biotic pollination services is poorly understood. We used the biologically and culturally diverse Nilgiri Biosphere Reserve in India to characterise the types of NTFP and crop products of 213 plant species and asses their degree of dependency on animal pollination. We found that 80 per cent of all species benefited from animal pollination in their reproduction, and that 62 per cent of crop products and 40 per cent of NTFP benefited from biotic pollination in their production. Further we identified the likely pollinating taxa documented as responsible for the production of these products, mainly bees and other insects. A lower proportion of indigenous plant products (39 per cent) benefited from biotic pollination than products from introduced plants (61 per cent). We conclude that pollinators play an important role in the livelihoods of people in this region.

Keywords: bees, crops, non-timber forest products, pollination, pollinators

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INTRODUCTION

Non-timber forest products (NTFP) are defined here as goods other than timber and firewood, of plant origin and derived from forests (De Beer & McDermott 1996). Crops and NTFP produce may be used directly, such as food, fibre, medicine and construction materials or processed further to yield oils, soap substitutes and other commodities, and these products may be traded for money or bartered for other goods and services (De Beer & McDermott 1996, Muraleedharan *et al.* 1997). The plant parts used are diverse and include, fruits, seeds, nuts, leaves, bark, roots, stems, gums and resins (Durst *et al.* 1994, Lopez & Shanley 2004).

Human populations have harvested NTFP for thousands of years, for subsistence and trade (Ticktin 2004). Recent meta-analyses of case-studies from a number of countries have illustrated some of the many variables that influence economic and ecological sustainability of NTFP harvest (Kusters *et al.* 2006, Belcher & Schreckenberg 2007). One major gap relates to the information available on the ecology of most NTFP (Belcher & Schreckenberg 2007) and in our understanding of the non-commercial NTFP.

Pollinators can have a positive impact on plants, that is, there is evidence of increased production, defined as increased fruit set, fruit weight and / or quality, seed number and / or seed quality, and / or increased pollen deposition (Klein *et al.* 2007). Biotic pollination can be essential (i.e., essential for reproduction), or where reproduction occurs through other methods (e.g., self- or abiotic pollination, or asexual reproduction), biotic pollination can still be beneficial by enhancing fruit / seed quantity / quality, enhancing population viability and / or persistence, or by greater genetic diversity through outbreeding. Products from crops and NTFP may benefit from animal pollination in their production (e.g., fruits, seeds, pods) or the plant species itself may benefit from animal pollination in reproduction, even though the product itself may not result directly from pollination services (e.g., bark, roots, stems, etc.). Approximately 75 per cent of the global crops that are used directly as human food depend, at least in part, on animal-mediated pollination (Klein *et al.* 2007); and the majority of wild plants also require biotic pollination (Allen-Wardell *et al.* 1998, Kearns *et al.* 1998). In a study of tropical monsoon forests in Southeast Asia, Kato *et al.* 2008, found that 51 per cent (68 / 134) species were reported to be pollinated by bees. Despite the recognition of the general importance of animal pollination for crops and NTFP production, there is little systematic documentation of the proportion of crops and NTFP benefiting from the pollinators and the identity of the pollinators themselves (Ahmed *et al.* 2005, Klein *et al.* 2007).

The most important pollinators around the world are bees, but other insects (flies, butterflies, beetles, etc.), bats and birds also make significant contributions to biotic pollination (Buchman & Nabhan 1996). These pollinators provide an essential ecosystem service by contributing to human nutrition and welfare, however, the extent of this service is poorly understood. It is estimated that globally, pollination services to cultivated crops are worth €153 billion per annum, yet we have no similar estimate of the contribution to non-cultivated plants from which NTFP are derived (Gallia *et al.* 2009). Given the central role of pollinators in supporting livelihoods, and the fact that in many places around the world pollinators are under increasing threat from global change (Biesmeijer *et al.* 2006, Natural Research Council 2006), it is essential to understand and document the role of pollinators as a basis to conserve this component of biodiversity and ensure its continued contribution to indigenous livelihoods (Ahmed *et al.* 2005).

Ensuring linkages between conservation and the livelihoods of forest-dependent people and the biodiversity components they utilise, necessitates a good understanding of the natural resources. This is of special importance in regions like the Nilgiri Biosphere Reserve (NBR) in South India, which supports exceptional levels of both biological and cultural diversity. The NBR is home to more than 14 different Adivasi communities who harvest and depend on a wide variety of NTFP for subsistence and commercial use, and many of them also practise subsistence agriculture (Keystone 2007). As logging and hunting are prohibited within the NBR, NTFP and crops are the most important natural resources used in this area.

As a first step towards better understanding the linkages between biodiversity, NTFP and the crops, we have used the NBR in India as a model system to explore the role of pollinators in relation to crops and NTFP. We aim to characterise the proportion of crops and NTFP which benefit from biotic pollination, identify their probable pollinators and describe the plant parts and use of the products. Specifically we test the hypotheses: (1) cultivated crop products benefit more from biotic pollination than NTFPs, as has been found in other studies (Klein *et al.* 2007; Kato *et al.* 2008); (2) introduced crops and NTFPs benefit more from pollinators than indigenous plants, as reported elsewhere (James and Pitts-Singer 2008); (3) bees are the most important pollinator taxa responsible for crop and NTFP pollination in NBR, as they are in other regions of the tropics (Roubik 1995).

MATERIALS AND METHODS

The Nilgiri Biosphere Reserve (NBR) lies between 10° 45'N to 12° N and 76° E to 77° 15' E with a total area of 5,520 km^2, spread across the three southern states of Karnataka, Kerala and Tamil Nadu. Altitude within the NBR varies from 250 m to 2650 m, and presents a diversity of vegetation types, ranging from tropical evergreen to thorny scrub. At least four of the major rivers of South India originate from this region — the Bhavani, Moyar, Kabini and Chaliyar rivers.

A database for the NBR was compiled by Shiny Rehel using the species lists of crops and NTFP listed in Keystone Foundation (2006), Keystone Foundation (2007), Manivasakam (2003) & Rajendran *et al.* (2008). For each species additional information was included for the type of product(s) used by local people, what the product(s) were used for, whether they were traded, whether production of the plant product benefited from biotic pollination, whether the plant species itself benefited from biotic pollination for reproduction, whether the species was indigenous to NBR or introduced, and the documented pollinators for the species. For the pollinators, we included both direct empirical studies demonstrating that visitors were the pollinators, and also those studies reporting that observed visitors were the possible pollinators; some caution was needed, as not all observed visitors were pollinators, but for our broad scale study we included the best available evidence at the time. Details of the categories used are summarised in Table 1, and the database is available as supplementary online material. Where information was not available for a particular species it was assigned as unknown. The database was analysed by summing counts and calculating percentages for different categories, and comparisons between counts for cultivated versus NTFP species and indigenous versus introduced species were tested using an χ^2 test in Minitab v15.

RESULTS

For the NBR, in our database, we identified 74 cultivated species and 139 NTFP species. Overall 47.9 per cent of the plant products used by local people benefited from biotic pollination (62.2 per cent of the cultivated products and 40.3 per cent of the NTFP products); products from cultivated plants more often benefited from biotic pollination than products from NTFP (χ^2 = 32.51, d.f. = 2, P < 0.001; Figure 1a). Irrespective of whether the plant product benefited from insect pollination or not, 80.3 per cent of all the species were reported as being biotically pollinated (Figure 1b; 82.4 per cent of the cultivated species and 79.1 per cent of the NTFP species), but there was no significant difference in the numbers of cultivated and NTFP species benefiting from pollination ($\chi^2 = 5.21$, d.f. = 2, $P = 0.074$). Considering only the fruit products, most cultivated plants (88.2 per cent) and NTFP (89.4 per cent) benefited from biotic pollination, with no evidence that the plant type and degree of benefit were related ($\chi^2 = 0.02$, d.f. = 1, $P = 0.874$).

In our study, among the plants, 128 were indigenous to the NBR and 85 were introduced. Most of the NTFP were indigenous to the area (117 / 139 species), while most of the

Table 1

Categories in the database, definition of terms and resources used

Category	Definitions	Source
Species	Scientific binomial for the species.	The NTFP plant list and crop plants of the NBR was complied from: Manivasakam S. (2003) Studies on Non Timber Forest Products in the Eastern region of The Biosphere Reserve. MSc thesis, Tamil Nadu Agricultural University. Keystone Foundation (2006) Forest plants of the Nilgiris, an illustrated field guide. Keystone Foundation (2007) Honey trails in the Blue Mountains. Rajendran R., Lalitha M., Sivamma S., (2008) Sigur Wild food booklet, Keystone Foundation. Unpublished data from 'Bees, biodiversity and livelihood' project, Keystone Foundation. Unpublished data from 'Land development and Sigur water resource project', Keystone Foundation.
Type	The plant was categorized as 'NTFP' or 'cultivated' species. Species which are not managed in any way are considered as NTFP. Cultivated species are found in villages and managed in some way.	Manivasakam S. (2003) Studies on Non Timber Forest Products in the Eastern region of The Biosphere Reserve. MSc thesis, Tamil Nadu Agricultural University.
Product	The part of the plant that is harvested or collected for human use or consumption: fruits, seeds, nuts, pods, bark, shoots or stems, leaves, flowers, gum or resin, bulbs or roots or tubers, rhizomes and the whole plant.	Manivasakam S. (2003) Studies on Non Timber Forest Products in the Eastern region of The Biosphere Reserve. MSc thesis, Tamil Nadu Agricultural University.
Use	The use of the product as: food, medicine, construction material, fibre, fumigation, oil extraction, perfumes or soap.	Manivasakam S. (2003) Studies on Non Timber Forest Products in the Eastern region of The Biosphere Reserve. MSc thesis, Tamil Nadu Agricultural University.
Trade	Whether the product is traded or not.	Anita Varghese, Shiny Rehel, Keystone Foundation pers. comm.
Product benefitting from pollinators	The product benefitting, at least in part, from pollinators for its production (yes, no, unknown).	http://delta-intkey.com http://en.wikipedia.org/wiki/List_of_plants_pollinated_by_bees http://gears.tucson.ars.ag.gov/book/chap6/veg. http://www.actahort.org/books http://www.amjbot.org http://www.cabicompendium.org http://www.crfg.org/pubs/ff/mango.html http://www.fao.org http://www.hort.purdue.edu/newcrop/morton/pomegranate.html http://www.pollinator.org/Resources/Pollination per cent20Handbook.pdf http://www3.interscience.wiley.com Klein *et al*. (2007)
Species benefitting from pollinators	The plant species benefitting, at least in part, from pollinators for its reproduction irrespective of whether the product benefits from biotic pollination (yes, no, unknown).	Geetha Nayak pers. comm. http://delta-intkey.com http://en.wikipedia.org/wiki/List_of_plants_pollinated_by_bees http://gears.tucson.ars.ag.gov/book/chap6/onion.html http://satishphadke.blogspot.com http://waynesword.palomar.edu/gallfig.htm http://www.amjbot.org/cgi/reprint/92/2/370 http://www.amjbot.org/cgi/reprint/94/2/260.pdf http://www.biodiversityexplorer.org/plants/fabaceae/arachis_hypogaea.htm http://www.cifor.cgiar.org http://www.endemia.nc/files/Cycads_and_Beetles.pdf http://www.pfaf.org/database/plants.php?Arachis+hypogaea, http://www.springerlink.com/content/u1777u2671h3rlt4/ http://www.worldagroforestrycentre.org Klein *et al*. (2007)

Table 1 (contd...)

Pollinators	Reported likely pollinators for the plant species: bees (sub-divided into honeybees (sub-divided into *Apis cerana*, *A. dorsata*, and *A. florea*), stingless bees and solitary bees); other insects; birds and bats.	Geetha Nayak pers. comm. Grubben G.J.H. and Denton O.A. (2004) Plant Resources of Tropical Africa. Backhuys Publishers. http://aob.oxfordjournals.org/cgi/content/full/98/2/317/TBL7 http://cals.arizona.edu/desertlegumeprogram/pdf/aridus16-1.pdf http://database.prota.org/PROTAhtml/Celosia per cent20argentea_En.htm http://delta-intkey.com http://en.wikipedia.org/wiki/List_of_plants_pollinated_by_bees http://envfor.nic.in/divisions/re/completed_proj.pdf, htmhttp://www.biodiversityexplorer.org/plants/fabaceae/arachis_hypogaea.htm http://florawww.eeb.uconn.edu/pol_bat.html http://gears.tucson.ars.ag.gov/book/chap6/onion.html http://satishphadke.blogspot.com/ http://waynesword.palomar.edu/gallfig.htm, http://www.actahort.org/books/446/446_9.htm, http://www.pollinator.org/Resources/Pollination per cent20Handbook.pdf http://www.aloe-vera-advice.com/aloe-vera-plants.html http://www.amjbot.org/cgi/reprint/94/2/260.pdf http://www.beekeeping.com/articles/us/small_beekeeping/project_planning.htm http://www.biodiversityexplorer.org/plants/fabaceae/arachis_hypogaea.htm http://www.cababstractsplus.org/google/abstract.asp?AcNo=20053143160 http://www.cabicompendium.org http://www.cifor.cgiar.org/publications/pdf_files/Books/NTFPAsia/TOC-Chapter5.PDF http://www.crfg.org/pubs/ff/fig.html http://www.crfg.org/pubs/ff/mango.html http://www.ecologyandsociety.org/vol13/iss2/art11/ http://www.hear.org/starr/hiplants/reports/pdf/solanum_torvum.pdf http://www.hort.purdue.edu/newcrop/morton/emblic.html#Pollination http://www.ias.ac.in/currsci/jun252002/1466.pdf http://www.ias.ac.in/jarch/currsci/70/00000338.pdf http://www.ibiblio.org/pfaf/cgi-bin/arr_html?Amaranthus+spinosus http://www.iisc.ernet.in/currsci/feb102005/350.pdf http://www.illinoiswildflowers.info/prairie/plantx/an_sunflowerx.htm,3 http://www.newcrops.uq.edu.au/listing/species_pages_S/Sida_rhombifolia.htm, http://www.pfaf.org/database/plants.php?Amaranthus+spinosus http://www.plantapalm.com/Vce/biology/pollination.htm http://www.plantzafrica.com/plantcd/cleomegyn.htm http://www.pollinator.org/Resources/Pollination per cent20Handbook.pdf http://www.rbgsyd.nsw.gov.au/science/hot_science_topics/Ecology_of_Cumberland_Plain http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6WH9-4GSC2JR- http://www.worldagroforestrycentre.org/sea/Products/AFDbases/af/asp/SpeciesInfo.asp?SpID=618 http://www.worldagroforestrycentre.org/sea/Products/AFDbases/AF/asp/SpeciesInfo.asp?SpID=914 http://www2.biology.sc.chula.ac.th/web per cent20of per cent20NHJCU per cent20PDF/6-2,75-82.pdf Keystone Foundation (2006) Forest plants of the Nilgiris, an illustrated field guide. Klein *et al*. (2007) Nicola Bradbear, pers. obs. Shiny Rehel, pers. obs. Srivastav (1993)
Origin	Whether the plant is indigenous or introduced into the NBR. Plants that occur naturally in the NBR are considered as indigenous. Plants that are not naturally occurring in the NBR but have been found in the NBR due to accidental or deliberate human activity are considered as introduced.	Gamble J.S. (1915) Flora of The Presidency of Madras. London: West, Newman and Adlard.

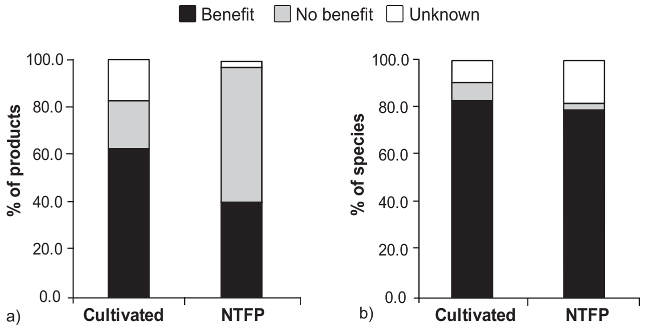

Figure 1

(a) The proportions of cultivated and NTFP products benefited, at least in part, by biotic pollination; (b) the proportions of cultivated and NTFP species benefited, at least in part, by biotic pollination

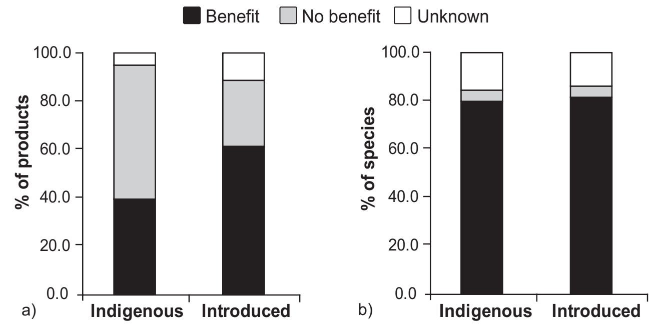

Figure 2

(a) The proportions of indigenous and introduced products benefited, at least in part, by biotic pollination; (b) the proportions of indigenous and introduced species benefited, at least in part, by biotic pollination

cultivated species were introduced (63 / 74 species); these two factors, plant type and origin, were strongly related ($\chi^2 = 96.73$, d.f. = 1, $P < 0.001$). Among the indigenous plants, 39.1 per cent of the products and 79.7 per cent of the species benefited from biotic pollination, whereas, among the introduced plants 61.2 per cent of the products and 81.2 per cent of the species benefited from biotic pollination (Figure 2). On the whole, introduced plant products benefited more from pollinators than the indigenous products ($\chi^2 = 17.10$, d.f. = 2, $P < 0.001$), while the indigenous and cultivated species benefited equally from pollinators ($\chi^2 = 0.09$, d.f. = 2, $P = 0.955$).

The plant species which benefited from pollination utilised a wide range of pollinator taxa (Table 2). Cultivated plants and NTFP were most commonly pollinated by bees and other insects, but rarely by birds and bats. Honeybees (*Apis* spp.) and solitary bees were the most frequent bee pollinators for both cultivated crops and NTFP, although both taxa are more commonly reported for crops. The overall pollinator community for cultivated plants and NTFP were different ($\chi^2 = 26.62$, d.f. = 2, $P = 0.002$). For those species where fruit products were used, most cultivated plants (79.5 per cent) and about half of the NTFP (53.1 per cent) were recorded as having bee pollinators and these two factors, plant type and frequency of bee pollination, were related ($\chi^2 = 6.47$, d.f. = 1, $P = 0.010$). Indigenous and introduced plants were fairly similar in the spectrum of the pollinating taxa associated with them ($\chi^2 = 16.97$, d.f. = 2, $P = 0.049$), again being dominated by bees and other insects, however, introduced plants appear to be more often associated with honeybees and solitary bees than indigenous plants.

The types of products collected or harvested from plants benefiting from pollinators are diverse (Table 3) and included: fruits, seeds, nuts, pods, bark, shoots, stems, leaves, flowers, gum or resin, bulbs, roots, tubers, or rhizomes and the whole plant. Fruits were the most commonly cultivated and harvested products (33 / 66), while fruits (46 / 122) and leaves (32 / 122) were the most commonly collected NTFP. Most pollinator-benefiting crops were used as food (Table 4: 56 / 61), whereas, NTFP yielded a wider array of use for products, the most common being food (45 / 109) and medicine (56 / 109). Nearly all cultivated products that benefited from biotic pollination were traded (52 / 61) while only about half of the NTFP were commonly traded (65 / 110).

DISCUSSION

This is the first study we know of, which attempts to systematically assess the level of benefits for both crops and non-timber forest products (NTFP) from biotic pollination, in an ecologically important area. Within the NBR we identified 213 plant species important to the local people, a third of which were cultivated and two-thirds of which were NTFP. Both crops and NTFP had a significant proportion of their products which benefited directly from pollinators, although crops (60 per cent) benefited more than NTFP (42 per cent). Even greater proportions of the species themselves benefited from biotic pollination (~80 per cent, even though the harvested products themselves did not rely directly on the pollinators as such). We can therefore conclude that the majority of products collected from the forests or those grown as crops in the NBR, greatly benefit from the provision of pollinator services. Similarly a great proportion of the world's crops also depend, at least in part, on biotic pollination (e.g., Klein *et al.* 2007), although a greater proportion of our NTFP benefited from biotic pollination than the plant species assessed in the tropical monsoon forests in Southeast Asia (Kato *et al.* 2008).

The majority of NTFP in our study were indigenous to the NBR, while most of the cultivated species had been introduced. The cultivated plants had a greater association with honeybees, which were usually considered as generalist pollinators and can readily use novel floral resources (Itioka *et al.* 2001, Thomas *et al.* 2009). Honeybees may have played an important role in ensuring that newly introduced crop species were productive, and may continue to contribute in the same way if further species are brought to the NBR. Of the indigenous plants ~40 per cent of the products benefited from pollinators, whereas, more than 60 per cent of the crop products benefited from

Table 2
Reported pollinating visitors to plants benefitting from biotic pollination in NBR

	Cultivated	NTFP	Indigenous	Introduced
Bees:	54	60	55	59
Honeybees:	37	20	19	38
Apis cerana	2	5	4	3
Apis dorsata	2	3	3	2
Apis florea	1	2	2	1
Stingless bees	13	4	5	12
Solitary bees	38	10	11	37
Other insects	37	45	42	40
Birds	4	6	5	5
Bats	3	2	2	3

Table 3
Types of products collected or harvested from plant species benefiting from biotic pollination

Product	Cultivated	NTFP
Fruit	33	46
Seed	13	4
Nut	3	0
Pod	2	0
Bark	0	14
Shoot/stem	0	1
Leaf	6	32
Flower	4	1

Table 4
Use of products collected or harvested from plant species benefiting from biotic pollination

Use	Cultivated	NTFP
Food	56	45
Medicine	0	56
Perfume	1	0
Construction	0	1
Fibre	1	3
Fumigation	0	0
Oils	3	1
Soap	0	3
Total	61	109

pollination by animals. This suggested that more cultivated products would be sensitive to the loss of pollination services rather than those obtained from the forests.

Insects were the most important taxa providing pollination services, and bees in particular were linked to the reproduction of many species. Honeybees and solitary bees were the most commonly documented pollinators, but stingless bees were also listed for several species. Many studies have observed bees to be key pollinators of a wide range of crops and wild flowers and the continued availability of bees is therefore essential in the NBR to ensure that crop and NTFP products are produced and continue to contribute to the livelihoods in the NBR.

Pollinators contributed to the availability of a wide range of products which are important components of local diets and provide a variety of medicines. Bees and other insects are therefore contributing directly to the nutrition, health and livelihoods of many indigenous people of the NBR. Bees and other insects must therefore be considered as a crucial component of biodiversity, delivering essential services to society.

Given that in many regions of the world pollinator declines have been observed and land use changes and climate changes are impacting the NBR, it is essential to understand the conservation needs of bees in the NBR and to ensure that suitable forage and nesting resources are made available to them, now and in the future. Only by managing bee habitats can the provision of pollinator-related products be ensured and the livelihoods of indigenous people be protected.

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