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Minireview

Ecosystem Services of Honey Bees; Regulating, Provisioning, and Cultural Functions

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Abstract Ecosystem services are often undervalued, largely because it remains outside of the market economy, we do not require monetary paying for these services. However, without this ecosystem service, not only human but also the ecology and environment in totality will be imbalanced. In this paper, we attempt to understand the roles of honey bee in the context of human well-being. We represent services of honey bee on the basis of functionality i.e. regulating, provisioning and cultural functions. The paper strongly advocates that human must fully appreciate ecosystem service, otherwise it may threaten human livelihood.

Keywords Api-products, Sustainability, Api-tourism, Nutrition, Functional food, Medicinal

INTRODUCTION

Ecosystem provides multiple benefits to humankind in terms of different goods and services which consist of ecosystem processes and component. The ecosystem services can be direct such as water supply, pollination, food production, and biological control; or indirect such as nutrient recycling, soil erosion control and waste treatment etc. (Stiling, 2002). On the basis of functionality, the ecosystem services may be classified as regulation functions (e.g. gas, climate, disturbance prevention, water regulation, soil retention, water supply, soil formation, nutrient regulation, pollination, biological control), habitat functions (e.g. suitable living place, suitable reproduction habitat), productions functions (e.g. food, raw materials, genetic resources), information functions (e.g. aesthetic, cultural, spiritual recreation, science and education) (de Groot *et al*., 2002; Wallace, 2007). However, as these services are largely outside of the market economy, they were or even are often neglected. One of the early pioneering works to estimate the world's economic services was attempted by Costanza *et al*. (1997) and calculated total ecosystem services 33,268 billion USD. The ecosystem services concept was highlighted and its needs are assessed by the (MEA) in the early 2000s (Millennium Ecosystem Assessment, 2005a). Due to the interventions by the human which create the change and regime shifts on climate, land cover, oceans, range land (Millennium Ecosystem Assessment, 2005a; Carpenter *et al*., 2006), agriculture and biodiversity (Tscharntke *et al*., 2005), and other supply chain for the services, it is imperative to conserve and make understand ecosystem service in terms of future perspective (Millennium Ecosystem Assessment, 2005b). Thus, understanding and appreciation of these ecosystem services may protect the ecological degradation. In this paper, we attempt to discuss the ecosystem services for human, obtained from honey bee.

Ecosystem services provided by honey bee comprises of several regulating, provisioning and cultural functions related to human well-being (de Groot *et al*., 2002; Jung, 2008; Liss *et al*., 2013; Oteros-Rozas *et al*., 2014). Not only domesticated but wild honey bees are also important in providing benefits to the human (Garibaldi

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et al., 2013; Matias *et al*., 2017). Regulating services by honey bee has a great value as major pollinating agents to enhance reproduction of the crop ultimately increasing the quality and quantity of food and feed (Klein *et al*., 2007; Jung, 2008; Eilers *et al*., 2011). Similarly, honey bee has an important role in maintaining the different floral diversity for the proper conservation of the ecosystem. The provisioning services provides bee products such as honey, pollen, propolis, royal jelly used as human food and therapeutic components and other api-products like bee wax (Oteros-Rozas, *et al*., 2014) as well as for livestock (Madras-Majeswska *et al*., 2015). Cultural services include apiculture tourism (Thapa, 2001; Ahmad and Partap, 2004; Arih and Korošec, 2015), religious values of bee products, further deepening the knowledge about science of honey bees and some inspirational insight (Cohen, 2006; Nakrani and Tovey, 2007) (Fig. 1).

REGULATING FUNCTIONS

1. Pollination and human health

Immense numbers of organisms are involved in the complex ecological interactions that made possible to keep food on our table. Pollinators share the most among them. Pollination is a process of transferring male gamete to female reproductive organ and is inevitable for plant reproduction, thus crop yield. While some plants are self-pollinated or wind pollinated, most flowering plants need help from pollinators to produce fruits and seeds. Seventy five percent of the 115 major crops grown globally are pollinator dependent and up to 35% of global annual agricultural production by weight is pollinator dependent (Klein *et al*., 2007). Not only the productivity or yield but also it improves the quality of the fruit leading to higher-value crops from the same yield (Klatt *et al*., 2013).

Pollination depends on the symbiotic relationship between pollinator and pollinated plants. Among insect pollinators honey bee has received the most attention and considered the major pollinator workhorse. However, a substantial volume of recent studies indicates that the native pollinators i.e. bumblebees, solitary wild bees provide essential reproductive service for wild as well as cultivated plants in virtually all terrestrial ecosystem. It was 1985 when first time De Jonge uncovered the economic benefits of using bumblebee for pollination of greenhouse tomatoes and subsequently funded the commercial bee rearing organizations (Velthuis and van Doorn, 2006). Today beside the largely managed honey

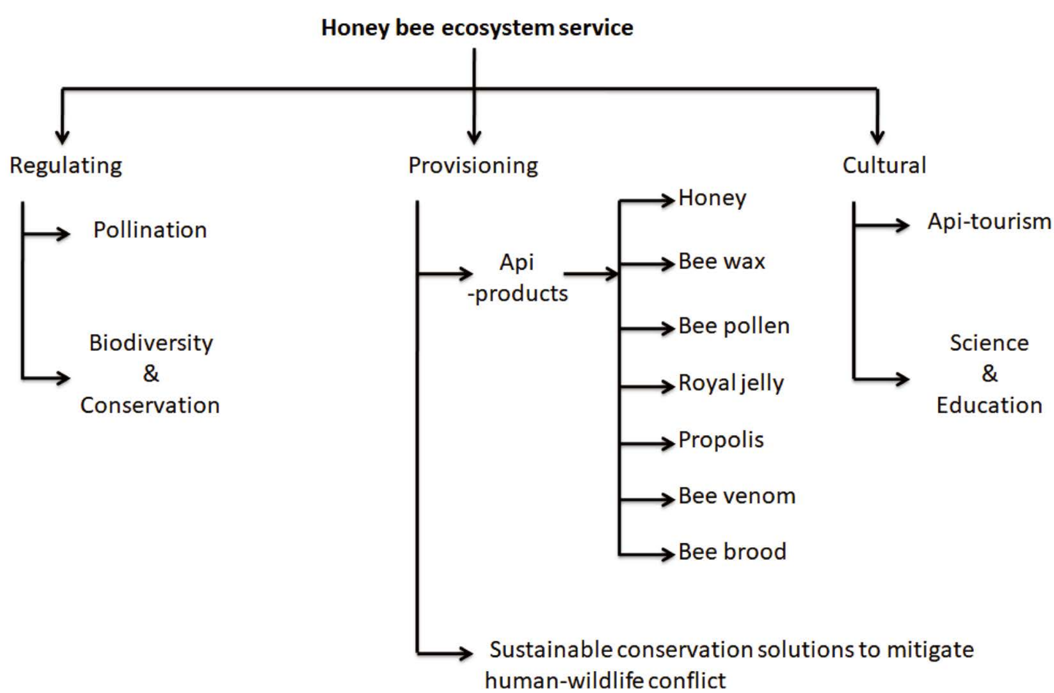

Fig. 1. Schematic representation of ecosystem services provided by honey bee.

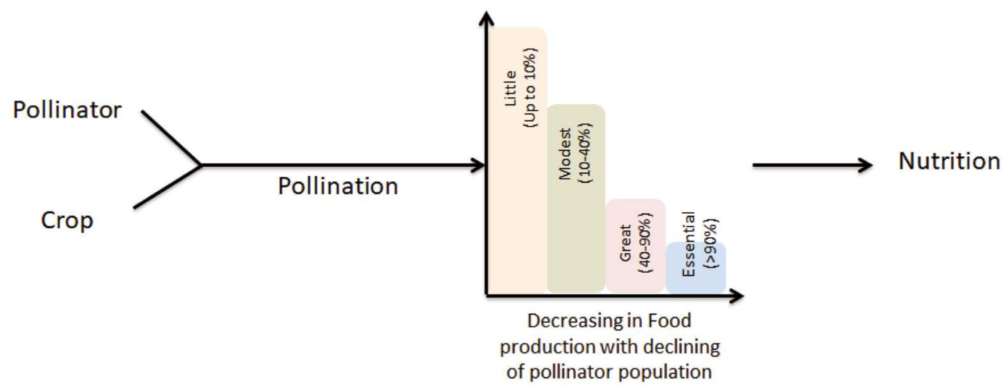

Fig. 2. Schematic diagram representing the relation between pollination and nutrition.

bee, bumblebees are also significant stakeholders of the commercial pollinator market.

Although there is a scope of argument on the subject of 'global pollination crises', studies provide evidences of pollinator population diminishing in some parts of the world like North America, few European regions (Potts *et al*., 2010; UNEP, 2010). Habitat deterioration including habitat degradation and fragmentation of natural habitat, higher pathogen prevalence, competition between native and invasive species, agricultural intensification leading to less plant diversity and climate change are the probable causes of pollinators' declination. The declination of pollinator population is likely to cause of lower yield of pollination dependent crops (Fig. 2). A recent study showed that global honey bee colony numbers were positively correlated with the little, modest and great pollinator dependent crops but negatively correlated with essential pollinator dependent crops (Ghosh and Jung, 2016). In turn, the disastrous declination of pollinator population could cause a dramatic increase in non-communicable and under-nutrition, primarily micronutrient deficient related disease burden (Smith *et al*., 2015; Ghosh and Jung, 2018). To cite a few examples, in Korea 37.3% of total vitamin A (RAE) and 27.5% of total folate are produced by pollinator dependent crops (Ghosh and Jung, 2018). Thus, it can be easily understood that pollination service is essential for the survival of human.

PROVISIONING FUNCTIONS

1. Api-products:

Honey: Started about 3000 years ago, beekeeping is known to almost all parts of the world today. The product of beehive which comes first in the mind is honey. Honey bee collects nectar and produces honey by a process which involves enzymes like invertase, glucose oxidase and catalase. Mentioned in the age old classical literatures and as well as modern scientific documentations, honey's therapeutic and nutritional value on account of its functional properties including antimicrobial, antioxidant efficacy is unquestionable (Khan *et al*., 2007; Mandal and Mandal, 2011; Cortés *et al*., 2011; Ajibola *et al*., 2012). An increasing trend is noticed for the total worldwide production of honey (Fig. 3A). The production of world honey bee rose to more than 1.8 million tons in 2018 from 0.7 million tons in 1961 (http://www.fao.org/faostat) (Fig. 3A). Many countries have established legal framework in order to ensure the quality or standard of honey. Moreover, international regulation or standard on the quality of honey has also been imposed. To elaborate, the permissible limit for moisture content of honey has been permitted up to 20% according to Codex standard. Codex standard also recommends electrical conductivity (EC) value to be within 0.8 mS/cM. In order to compliance the same standard, honey should contain fructose and glucose together 60 g. Also there is a recommendation for Hydroxy methyl furfural (HMF) content and other specifications of honey. In this context, it is worth mentioning that mostly standardization considers honey from *Apis mellifera*. The standardization of honey from honey bees other than *A. mellifera* still remains as an unfinished task.

Bee wax: Bee wax is the foundation of the bee colony and has vast arrays of use. Human have exploited the use of wax to their benefits. They are used in cosmet-

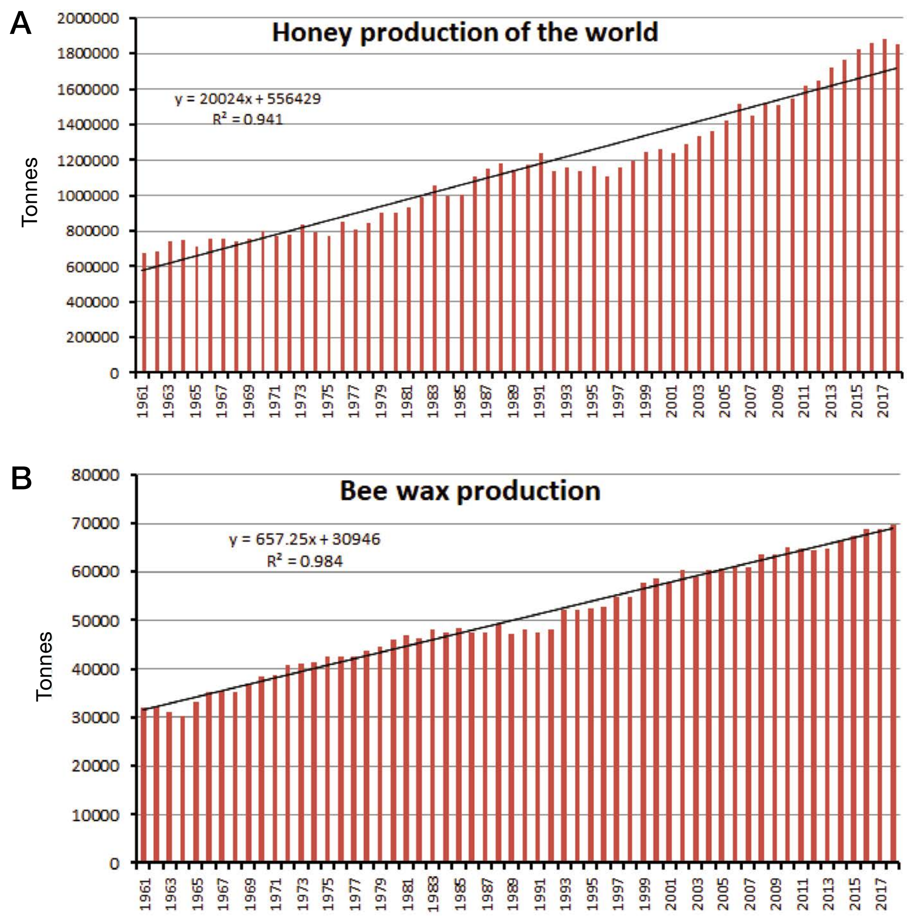

Fig. 3. A. Worldwide production of honey and trend of production during 1961 to 2018. B. Worldwide bee wax production and trend of production during 1961 to 2018 (Data obtained from http://www.fao.org/faostat).

ics, pharmaceuticals, art (metal castings and modeling, paintings), candle making, varnishes and polishes (Krell, 1996). Bee wax has been used in colors of the wall paintings (Birshtein *et al.*, 1975) and also used in wrappings for the covering mummies in Egypt (Benson *et al.*, 1978). The major proportion of the bee wax was consumed by the local beekeeper to make comb foundation. As the demand of wax increases over the years its production as well as value is also increasing over the years (Fig. 3B).

Bee Pollen: Bee pollen is another hive product which can be obtained very easily with the installation of pollen trap. Bee pollen is the primary source of nutrition including protein, fatty acids, sterols, minerals and vitamins for honey bees. Detailed examination of nutrient content and digestibility demonstrates bee pollen can be relevant to human nutrition especially as a nutrition supplement (Franchi *et al.*, 1997; Human and Nicolson, 2006; Szczêsna, 2006; Morgano *et al.*, 2012; Ghosh and Jung, 2017; Ghosh *et al.*, 2020a). As with the increasing awareness about organic food supplements, bee pollen is increasingly becoming popular. Similarly like honey, different countries already framed legal standardization for bee pollen intended for human use (Ghosh and Jung, 2017). Bee pollen is also known to have high antioxidant properties which encourage the research concerning the application of bee pollen as an agent preventing or alleviating harmful oxidative processes occurring in organisms or caused by different factors (Kocot *et al.*, 2018). Besides, bee pollen marketing could help enhancing the earning of small and medium scale bee keepers.

Royal Jelly: Young nurse bees produce royal jelly, a precious food for queen honey bee. Royal jelly is secreted from hypopharyngeal gland. Chemically, fresh royal jelly contains water (60 to 70%), protein (9 to 18%), carbohydrate (7 to 18%), lipid (3 to 8%), ash

(0.8 to 3%) minerals and vitamins (thiamin, riboflavin, pantothenic acid, pyridoxine, niacin, folic acid, inositol, and biotin) (Sabatini *et al*., 2009). A significant amount of 10-hydroxy-2-decenoic acid (10-HDA) is presents in royal jelly, exhibits immunomodulatory, antimicrobial and antitumor properties (Izuta *et al*., 2009; Sugiyama *et al*., 2012). Moreover, royal jelly also exhibits activities like of bio-stimulating and anti-fatigue (Kamakura *et al*., 2001), life prolonging and anti-stress and tranquilizing effect, anti-arteriosclerotic and heart-protecting, antibacterial, antiviral and anti-fungal effect, radiation protective, immune-modulating and anti-carcinogenic effect on different animal models (Manzo *et al*., 2015). Kashima *et al*. (2014) identified hypocholesterolemic protein, Major Royal Jelly Protein 1 (MRJP1) which increases the enzyme CYP7A1 responsible for the degradation of cholesterol in mice and also have broad pharmacological activities in humans (Tian *et al*., 2018). Recently royal jelly is becoming a better source of income as it is used in cosmetics and functional food industry.

Propolis: Exudates of plants as resin collected by honey bee are used in honey bee colony to seal the hive and for their antibacterial properties (Marcucci *et al*., 2001). These food products from the honey bee have profound significance not only for their nutritional value but also for their medicinal value. It has bacteriostatic (Bonvehí *et al*., 1994) effect with lots of phenolic compounds (Martos *et al*., 1997; Socha *et al*., 2014) having therapeutic application (Sforcin, 2016). They may act as an antioxidant, anti-inflammatory, antibacterial, antiviral, and anti-ulcerous activities (Viuda-Martos *et al*., 2008; Simone-Finstrom and Spivak, 2010). These kind of activities are mainly due to the phenolic compounds, flavonoids which are present in honey, propolis and even in royal jelly (Cushnie and Lamb, 2005; Fiorani *et al*., 2006).

Bee venom: Bee venom exhibits a wide range of therapeutic properties like neuroprotective, rheumatoid arthritis, tendonitis and muscle conditions such as fibromyositis and enthesitis and other complications (Doo *et al*., 2010; Hong *et al.,* 2010; Ali, 2012; Cherniack and Govorushko, 2018; https://www.webmd.com/vitamins/ai/ingredientmono-972/bee-venom, accessed 6th June 2020). Bee venom mainly contains melittin, apamine, phospholipase A2 etc. (Ali, 2012). However, to collect bee venom high throughput technology is required and often this is beyond the affordability and/or accessibility of small to medium scale bee keepers.

Honey bee brood as food: In the context of hive products or api-products, which is less well appreciated is the honey bees themselves. In our previous series of works we examined nutritional value of honey bee brood of different bee species as well as castes. Honey bee brood and adult would be an excellent source of nutrition with their higher or comparable protein enriched with amino acids, minerals but less fat content than that of conventional food sources (Hockings and Matsumara, 1960; Finke, 2005; Ghosh *et al*., 2016, 2020b, 2020c). However, we advocated processing of the brood in order to remove anti-nutrient contents of it (Ghosh *et al*., 2020c). In the light of rapid human population growth and unanticipated climate change insect eating is gaining attention as a sustainable way to feed the human population of the planet. In this context, it is remarkable that honey bee is the third most domesticated animal on the earth and has a long history compared to other candidates of insect farming. Moreover, brood farming has several advantages including the requirement of relatively small arable space, lower investment to set up hives etc. Bee brood is already eaten as a delicacy in many countries including Africa, Mexico, Thailand, Australia, Nepal etc. (Burgett, 1990; Wongsiri *et al*., 1997; Jensen *et al.,* 2016).

SUSTAINABLE CONSERVATION SOLUTION

Sustainable use of beehive fences in order to protect crops from wildlife is a success story today. The strategy has been suggested as a potential mitigation way (Scheijen *et al*., 2019). Although the strategy was implemented first in Tanzania, it has also been introduced in African countries like Botswana, Mozambique, Uganda, Kenya and Asian country Sri Lanka (https://wildtech.mongabay.com/2015/09/pushing-the-boundaries/, accessed 10th June 2020). Also it is being investigated about the implementation in India and Malawi. Human-wildlife conflict is very common in the forest associated areas. Often elephant and some other animal migrated to areas nearby protected areas and destroy the crop. In most cases, wildlife lost its life. Installation of beehive fences in the boundary effectively ensures less attack and thus decreasing crop loss.

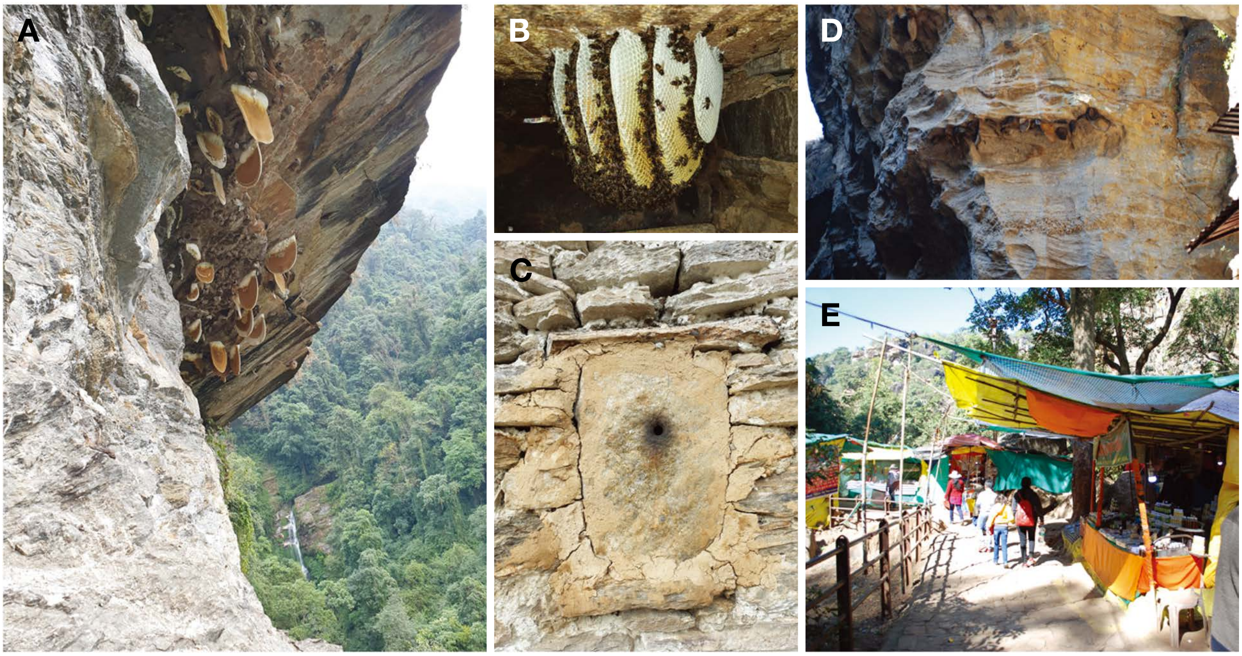

Fig. 4. Potential api-tourism centre Pokhara (Nepal) and Pachmarhi (India) A-C. Rock bee colonies in Pokhara (Nepal). Photo credit: Chuleui Jung. D. Rock bee colony in Pachmarhi (India), E. Selling of honey of rock bees in Pachmarhi (India). Photo credit: Sampat Ghosh.

Fig. 5. A. Commercial *Apis mellifera* apiary B. Wild honey bee, *Apis dorsata* colonies hanging on the prominent trees in Chiang Mai, Thailand. Photo credit: Chuleui Jung.

CULTURAL FUNCTION

Api-tourism: Besides other services, one of the newly emerged services that honey bee provides is in the form of tourism. Various recreational activities for the promotion of api-tourism and their modalities have been developed in different countries including educational tourism or as an integrated agro-tourism concepts with apiculture as a part of it (Valli, 1998; Thapa, 2001; Ahmad and Partap, 2004; Na-Songkhla and Somboonsuke, 2012; Wos *et al*., 2014; Madras-Majewska *et al*., 2015).

Apiculture tourism can benefit the community, and apiculture farmer to sustain their life as well as to uplift their livelihood and economic standard. Besides recreation, this intends to help enriching knowledge of common people, students, and scientist. Some traditional approach of the honey hunting of the wild bees has the potential to have the center of the attraction to the tourists at Nepal's high cliff mountain (Thapa, 2001; Ahmad and Partap, 2004; Oldroyd and Nanork, 2009; Strickland, 1982; Thapa *et al*., 2018), India (unpublished) and other countries (Mardan, 1994). The community level effort should be there to promote honey hunting tourism in a way which in turn helps in the conservation of the wild honey bee colonies of *A. laboriosa* and *A. dorsata* (Joshi and Gurung, 2005). Huge scope exists in the expansion of api-tourism (Figs. 4, 5). To cite few possibilities, establishment of trekking trail along the nesting site of wild bees can help integrate both adventure as well as apitourism; introducing apiculture museums, open-air museums of beekeeping also can be offered as apitourism (Wos, 2014); establishment of wellness center to promote api-therapy etc.

Inspirational: Nature has always inspired human to achieve different technological advances and human have acquired different efficient structures, tools, mechanisms, processes and other benefits. Honey bee comb structure for their maximum capacity of storage with minimum construction material led human to adopt a structure in important part of the wing, elevators, tail, the floor and many other parts to reinforce aeroplane (Paul *et al.,* 2002; Cohen, 2006) to maintain weight and balance. Another inspirational example of biomimicry was from the honey bee foraging allocation to different patches for maximizing the influx of nectar. A derived biomimetic algorithm from honey bee foraging behavior was used to manage the internet hosting servers (Nakrani and Tovey, 2007).

CONCLUSION

As we discussed earlier that the ecosystem services including the ecological services of honey bee are not actually paid, like our market economy, which is of course a reason behind the undervaluing these services. We advocate full appreciation for these services; otherwise ecological imbalance may threaten the environment and biodiversity including human survival.

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