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BIOECONOMICS OF POLLINATION SERVICES IN AGRICULTURE

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Abstract

Pollinators are an element of crop associated biodiversity, and provide an essential ecosystem service to both natural and agricultural ecosystems. In the case of agricultural ecosystems, pollinators and pollination can be managed to maximize or improve crop quality and yield. This paper deals with agriculture's dependence pollinators and pollination deficiency in agriculture. It outlines the Role of Native Pollinators in Agricultural Risk Management, The Economics of Pollinators and Reasons for Pollinators Decline. This paper makes an analysis of valuation of pollination services. This paper concludes with some interesting findings along with policy suggestions.

Introduction

More than one third of the world's agricultural output depends on animal pollination. Pollinators provide an essential ecosystem service to both natural and agricultural ecosystems. Pollination is the transfer of pollen between plants enabling fertilisation and sexual reproduction. There are two types of pollination, abiotic and biotic. Abiotic pollination takes place without the involvement of living organisms, for example, where pollen is transported by wind. Biotic pollination is the result of the movement of pollen by living organisms; it is the most common form of pollination and accounts for an estimated 90 per cent of pollination of all flowering plants.

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Biotic pollination: a successful symbiosis of plant and insect the sexual reproduction of plants mostly requires the transfer of pollen from one flower to another of the same species. There are plant species and plant varieties which are able to self-fertilise, but the exchange of genetic material between different individuals is the most common form of sexual reproduction amongst plants.

Pollination is a keystone process in both human managed and natural terrestrial ecosystems. It is critical for food production and human livelihoods, and directly links wild ecosystems with agricultural production systems. The vast majority of flowering plant species only produce seeds if animal pollinators move pollen from the anthers to the stigmas of their flowers. Without this service, many interconnected species and processes functioning within an ecosystem would collapse.

In agro-ecosystems, pollinators are essential for orchard, horticultural and forage production, as well as the production of seed for many root and fibre crops. Pollinators such as bees, birds and bats affect 35 percent of the world's crop production, increasing outputs of 87 of the leading food crops worldwide, plus many plant-derived medicines. It has been estimated that at least 20 genera of animals other than honeybees provide pollination services to the world's most important crops. For human nutrition the benefits of pollination include not just abundance of fruits, nuts and seeds, but also their variety and quality; the contribution of animal-pollinated foodstuffs to human nutritional diversity, vitamin sufficiency and food quality is substantial.

Crops produce optimally with a suite of pollinators possibly including, but not limited to managed honeybees. A diverse assemblage of pollinators, with different traits and responses to ambient conditions, is one of the best ways of minimizing risks due to climatic change. The "insurance" provided by a diversity of pollinators ensures that there are effective pollinators not just for current conditions, but for future conditions as well. Resilience can be built in agroecoystems through biodiversity.

Agriculture's Dependence on Pollinators

Naban and Buchmann (1997), note that animal pollinators include many insect species, as well as several species of birds and bats. NRC (2007), reports that animal pollination of agricultural crops is provided by both managed and wild pollinators. European honey bees (Apis mellifera) are the most common managed pollinator species, which possess several characteristics that make them good pollinators. First, they are generalist pollinators that are physically capable of pollinating many different plant species. Second, they exist in large, perennial colonies with up to 30,000 individuals that are available for crop pollination year round. Third, they are able to forage over large distances, so that their placement within large monoculture fields allows them to provide pollination services over a wide area. Fourth, they communicate with other members of the hive regarding location of food sources, making them highly efficient pollinators. And, finally, honey bees produce honey, a valuable, commercially-marketed product.

As per the reports by Veddeler et al. (2008) and Klein et al. (2003) wild pollinators are also important for agricultural production. Although honey bees can pollinate many plant species, they are not always the most efficient pollinator on a bee-per-plant-visit basis. For example, yucca plants are highly dependent on yucca moths for their pollination. As per the report by Kearns et al. (1998), principal pollinators vary by plant species, geographical location, and time of year. It is evident from the work of Kasina et al. (2009) that in many developing regions; wild pollinators are the sole provider of pollination services available to small scale farmers because of the high costs associated with maintaining managed colonies. It is evident from the work of Greenleaf and Kremen (2006) and Klein et al. (2003) that wild and managed pollinators can also have complementary behavioural relationships which increase the efficiency of pollination.

Pollinator dependency is a measure of the level of impact that animal pollination has on the productivity of particular plant species. Klein et al. (2007) reviewed the literature on animal pollination and developed a classification system for animal pollinator dependency

1. essential – production reduced by ≥ 90per cent without pollinators
2. great – production reduced by 40 to <90per cent
3. modest – production reduced by 10 to <40per cent
4. little – production reduced by >0 to <10per cent

5. none – no reduction in production
6. unknown – no literature available.

It is evident from the work of Klein et al. (2007) that 87 out of 115 global primary food crops require some level of animal pollination. The level of pollinator dependency varies dramatically among crops, with the highest level of dependence found predominantly in fruits, vegetables, and nuts. Crops that are essentially dependent on animal pollination include Brazil nuts, cantaloupe, cocoa beans, kiwi fruit, pumpkins, squash, vanilla, and watermelon. Many crops have reduced production in the quantity or quality of the plant part consumed directly by humans, while other crops have reduced production of seeds that are used to produce the vegetative parts of plants that humans consume.

Pollination Deficiency in Agriculture

In Malaysia, labor costs for hand pollination are rising sharply, found a solution to its shortage of pollinators for oil palm, Elaeis guineensis. Syed (1979) studied the pollination of this important crop plant in its native West Africa and worked out the relationship between the pollinating weevils, Elaeidobius spp., and the inflorescences of the male and female palms. As per the report by Syed et al. 1982) Elaeidobius kamerunicus was released in Malaysian oil palm plantations, where it rapidly became established and spread. Kevan et al. (1986) report that the result continues to be the sustainable and sufficient pollination of crops whose harvests exceed those previously produced by hand pollination, with savings of millions of U.S. dollars per year.

As per the report by Banda and Paxton (1991), placing pollinators into a novel habitat to enhance crop production is the introduction of bumble bees into hothouses to pollinate tomatos, Lycopersicon esculentum, in Europe and North America. Morandin (2000) describes the efforts being made to solve the remaining technological problems related to hothouse pollination. The value of "bombiculture" for producing hothouse tomatos and other fruit has not been assessed, but must amount to millions of dollars worldwide.

The catastrophic effects of recently introduced parasitic mites on honey bees have changed the face of apiculture in North America. Colony mortality and intensive management have made it more expensive to keep bees. The number of beekeepers has declined, as has the number of colonies being kept all over North America. Other pests also threaten to make beekeeping more costly and difficult. Pollination has been adversely affected, and growers have reported difficulties in obtaining services for crops such as blueberries in Maine, pome fruit in the northeastern United States and Canada, almonds in California, field cucumbers in the eastern United States and Canada, and hybrid seed production in western Canada.

Siebert (1980), estimated the revenue losses to both almond growers and honey producers in California resulting from a pesticide-induced decline in the numbers of pollinators; Olmstead et al. (1987), reported the historical and economic effects of the addition of pollinators on the production of alfalfa seed; and Cox et al. (1991), show that the demise of fruit bats (Megachiroptera) through overhunting in South Pacific islands has reduced the pollination and fruit yields of some traditional harvests. No matter what their cause, would we expect anything different to result from pollinator declines elsewhere?

Role of Native Pollinators in Agricultural Risk Management

Agricultural crop yields vary each year and are affected by many types of risk, including drought, pests, frost, and extreme weather conditions. A common risk management tool used by farmers is the diversification of farm revenue. Diversification strategies include combining crops and livestock, a mix of wholesale and direct marketing, or planting a mixture of crops. The goal is to reduce the variability in household income. Farmers may also rely upon crop insurance or on household members obtaining off-farm employment.

Increased attention is going towards incorporating both native insects and honey bees for agricultural pollination as a way to manage risk. Investing in native pollinator habitat could be an appealing option for a risk-averse farmer to increase the probability of maintaining a steady net income from squash production. A diversified approach to pollinating one that includes wild insects in addition to managed honey bees will increasingly become an essential tool in a farmer’s risk management tool kit.

A growing amount of research is showing that the inclusion of native pollinators in an agricultural production system can benefit agricultural risk management in the following ways. Maintain higher yields, improve yield quality and serve as a form of crop insurance

The survival of a bee colony depends upon many factors, including the availability of suitable food in sufficient quantities. The availability of the right amount of the right foodstuff at the right time is for example dependant on a certain arrangement of local agricultural landscape elements relating to crop type and coverage, availability of meadows and non-farmed land such as field margins, buffer strips and natural areas.

In addition, the local agricultural landscape reflects the economy. If the market for a certain crop changes, so too may the intensity of it's cultivation in a given area. The local agricultural landscape may also be suddenly devastated due to a natural disaster such as flood or drought, or more gradually through natural and human adaptation to climate change. When investigating the driving forces of changes to pollinator populations, attention is often directed only to ecological factors; this is short sighted and does not consider the reality of multi-level causality, nor sufficiently reflects the processes that influence biodiversity.

Klein et al. (2007) found that 87 crops, that is 70per cent of the 124 main crops used directly for human consumption in the world, are dependent on pollinators. It is evident from the work of Winfree et al., (2008) that insect pollination is both an ecosystem service and a production practice used extensively by farmers all over the world for crop production. It is an ecosystem service in that wild pollinators, in particular wild bees, contribute significantly to the pollination of a large array of crops. It is evident from the works of McGregor, 1976; Olmstead and Wooten, (1987) that honeybees, bumblebees and a few other bee species are purchased or rented by farmers in many countries to supplement the local pollinator fauna. This practice suggests that there is already not enough wild pollinators to insure adequate pollination of all crops throughout the year in these countries. Yet the abundance and diversity of wild bees as well as the abundance of honeybees are now declining and some species are clearly at risk. The current decline of insect pollinator populations emphasizes the need to better assess the potential loss in terms of economic value that may result from this trend and the possible ultimate disappearance of pollinators, and to estimate the level of vulnerability of the world agriculture to insect pollinators.

Two main ways have been used to date to assess the monetary value of pollinators. The first one consists in simply assessing the total value of insect-pollinated crops. Since the production of most crops is only partially reduced in the absence of insect pollinators, a second more refined approach to improve the previous estimate has been to introduce a dependence ratio that takes into account the real impact of insect pollinators on crop production. This dependence ratio enables the calculation of the production loss in case of a complete disappearance of pollinators, and the economic value of insect pollination service is assimilated with the corresponding loss of crop value. Thus the monetary assessment is directly related to reported values of the dependence of crop production on the level of insect pollination.

As per the report by Klein et al., (2007) there is a need to quantify the economic loss that could result from the total disappearance of insect pollinators on world agricultural output. Due to the many crop species and the heterogeneity of the structure of the agricultural production, the vulnerability to pollinator decline is likely to vary widely among the different continents and regions. There is a need to provide a measure of the vulnerability of the regional and world agriculture when confronted to the decline, or even the total disappearance, of insect pollinators. It is essential to compare the production and consumption of insect pollinated crop categories at the regional and world scale in the face of pollinator loss in order to draw some insight on potential local shortages and impacts on trade.

The Economics of Pollinators

The inadequacy of pollinator forces for agricultural production can be offset by providing services through imported pollinators, encouraging local populations to grow, or both. However, cost-benefit analyses for pollination services in agriculture are not readily available. Some cropping systems that would lend themselves well to such studies are alfalfa seed production, hothouse tomato production, some small berry and tender fruit crops, field cucumbers and melons, almonds and other orchard crops, and specialty production systems hybrid and horticultural seed production.

When studying apple production in Ontario, Kevan (1997) calculated roughly that providing about one hive of honey bees per hectare resulted in about one extra seed per apple, which produced larger and more symmetrical apples. These improved apples were estimated to provide marginal returns of about 5–6per cent, or about Can.$250/ha, compared to an orchard without honey bees. The cost of pollination services at that time was about 1per cent of production costs, and the greater yield represented a return to the grower of 700per cent of the cost of pollination services. Cane (1996) assessed the value of individual wild bees (Habropoda laboriosa) as pollinators of rabbiteye blueberry (Vaccinium ashei) at about U.S.$20.00. These models represent valuable and practical approaches to evaluating pollinators as an agricultural production cost with huge potential benefits. Unfortunately, the economics of bombiculture and hothouse tomato production seem to have been set artificially by the high cost of the alternative of hand pollination.

Reasons for Pollinators Decline

Despite these advances in our knowledge, the comparative lack of information on insects, compared to birds or mammals, that is accessible to decision makers concerns many scientists, because insects are by far the largest category of pollinators. Yet, due to their small size and inconspicuous nature, declines in insect species can go unnoticed until they approach local extinction. While species of native pollinators that visit agricultural crops are well documented, researchers are continually surprised as studies of native plants reveal new insects as pollinators. Unfortunately, these plant and pollinator species appear to be declining at a far greater pace than scientists are identifying their relationships.

The growing evidence of localized declines of pollinators is a cause for concern. The National Academy of Sciences noted that declines in many pollinator groups are associated with habitat loss, fragmentation, and deterioration; diseases and pathogens; and pesticides. The resulting impact on pollinator-dependent flowering plants could be devastating. In fact, the World Conservation Union predicts that 20,000 flowering plant species will disappear in the next few decades. While pollinator declines are not the sole cause of these plant extinctions, and few plant-pollinator systems are absolutely obligate between two species, large-scale losses of either flowering plants or pollinators are likely to result in cascading declines within both groups.

As per the report by Buchmann, S.L. (1996), there is not enough information available to predict the severity of the ongoing disruption to pollinator activity, yet the potential for significant and irreplaceable losses of biodiversity through cascading extinction is very real. The notion of a global disruption in pollination systems is not currently supported by empirical evidence, it is suspected that the well-documented localized declines are symptomatic results of the more wide-scale losses in biological diversity. It should come as no surprise that significant causes of both declines are often very similar: habitat loss, fragmentation and modification; agricultural and grazing practices; pesticide use; and the introduction of non-native species. **Habitat Loss,**

Fragmentation and Modification

It could be noted that habitat loss and fragmentation are the biggest problems for pollinators. However research in this area is limited, experts increasingly recognize the dependence of wild pollinator populations on appropriate habitat. It is evident from the work of Rathcke, B.J., and E.S. Jules (1993) that as habitat area decreases, abundance and diversity of insect pollinators also decrease.

Habitat loss and fragmentation affect pollinators in two ways. First, pollinators have basic food requirements. The availability of a variety of native plants is important because not all pollinators can gain access to the nectar found in introduced flowers. As per the report by Kearns, C.A., and D. Inouye (1997), pollinators also depend on the availability of various flowering plants throughout a season. Habitat loss can negatively affect the timing and amount of food availability, thereby increasing competition for those limited resources.

It is evident from the work of Scott, J.A. (1986) that loss of habitat can also disrupt the nesting or egg-laying requirements of pollinators. For example, some caterpillars are like the endangered Karner Blue, Lycaeides melissa samuelis, which feeds only on wild lupine (Lupinus perennis). Most bees also have specific conditions for nesting, such as bare soil or beetle-riddled snags. Development pressures from human activity and land management methods decrease the availability of caterpillar host plants, remove suitable bee nesting habitats, and modify the remaining habitats in other ways across the landscape.

Changing landscapes may also introduce positive features for pollinators. It is evident from the work of Cane, J.H., and V.J. Tepedino (2001) that the compacted soils of roadsides can be favoured by ground-nesting bees and wasps, wooden buildings and fences provide nest sites for other bees, and gardens and parks can offer foraging or butterfly egg-laying sites, although these benefits likely do not outweigh the losses of natural habitat from other human activities especially with rare or specialist pollinators.

Whereas habitat loss can seriously impact all pollinator organisms, increased fragmentation of habitats is particularly troublesome for those pollinators that travel great distances. Migratory pollinators, such as the monarch butterfly, the rufous hummingbird, and the lesser long-nosed bat, travel hundreds or thousands of miles each year as the seasons change. These trips require high levels of energy, and it is critical for the migrants to have consistent food resources all along the way. Fragmentation of habitat increases the distance between suitable food and shelter sites along migratory routes, thereby disrupting the journey. Some scientists believe that if fragmentation continues at its current rate, many migratory corridors will soon be closed.

Agricultural and Grazing Practices

In addition to development pressures that result in habitat loss and fragmentation, modern agricultural practices have increasingly made farms a poor habitat for wild pollinators. It could be noted that monoculture plantings, the removal of fencerows and buffer strips to maximize growing areas, and the use of hybrid seeds are common practices on farms. Monoculture farming and the removal of buffer strips reduce suitable habitat for wild pollinators. A study of the margins of agricultural fields pointed out that small area with native flowering plants, such as fencerows, could be effective in attracting and maintaining stable pollinator populations. Cumulatively, today's agricultural practices not only disrupt wild pollinator activity, but they also increase our dependence on costly managed honey bee colonies.

Grazing is also a threat to pollinators. Sugden, E.A. (1985) conducted a study of grazing practices in California and found evidence of sheep removing pollinator food resources, destroying underground nests and potential nesting sites, and direct trampling of bees. This evidence of pollinator disruption is exacerbated by the notion that sheep, cattle, and other grazing animals depend on insect-pollinated legumes, such as alfalfa and clover, for forage.

Pesticides Use Behaviour

Heavy reliance on a broad spectrum of pesticides by both the agriculture industry and individual homeowners poses yet another major threat to pollinators. It is evident from the work of Kevan, P.G. (1975) that insecticides affect pollinators directly through unintentional poisonings, and herbicides affect them indirectly through a loss of insect forage and other wildflowers important in maintaining some insect populations. While a significant hazard to all pollinators, the increased dependence on pesticides is particularly problematic for managed honey bees whose exposure is greater due to their use as crop pollinators. Despite efforts to raise awareness among farmers, beekeepers continue to report many pesticide and herbicide poisonings of honey bees each year. The physiological impacts of pesticides on native and honey bees are fairly well known but the effect on agricultural production is less well-known. Kevan (1997) found that loss of pollinators following application of the organophosphorous pesticide Fenitrothion resulted in blueberry crop yields in New Brunswick, Canada significantly below those of neighbouring Nova Scotia and Maine.

Even when applied as regulated, pesticides undeniably create significant hazards for pollinators. Unfortunately though, it is too often the case that pesticides are overused and applied carelessly, reaching unintended areas and exacerbating their impact. For example, in the case of aerial applicators, factors such as wind and human carelessness can greatly influence the actual coverage area of an applied pesticide, jeopardizing pollinators inhabiting areas within and adjacent to agricultural fields. This problem emphasizes the importance of buffer strips in agricultural areas, not only as a critical habitat for pollinators, but also as protection from pesticide oversprays.

Introduced Species

For hundreds of years nonnative species, including plants, mammals, insects, and pollinators, have been introduced both intentionally and inadvertently to new habitats. In some cases the effects are beneficial or benign, but introduced species can also have serious effects on their new ecological systems. As per the report by Gross, C.L., and D. Mackay (1998) an introduced pollinator is the European honey bee, which has been imported to virtually every corner of the world. Despite its well-documented benefits to commercial agriculture, there is evidence that the honey bee has disrupted native pollination systems through competition for floral resources, honey bees reduce the abundance of native pollinators. Native species, which have often co-evolved with local plant species, are in many cases more effective pollinators of crops and native wildflowers than the exotic honey bee. Introduced pollinators can also disrupt the reproduction of native plant species and facilitate the spread of invasive plants. For example, the fig wasp was introduced into California at the beginning of the twentieth century. Its introduction caused some existing non native fig trees to produce fruit and spread as pests throughout the region.

Pollination activity is also disrupted by other introduced insects and mammals. Pratt, T. (1999) reported that in Hawaii, native bees, moths, and the majestic but highly endangered silversword plant are at risk of extinction from the introduced Argentine ant. The spread of wild pigs onto the Hawaiian Islands has also destroyed critical habitat for endangered flowering plants and their pollinators, including the crested honeycreeper.

Introduced pathogens and parasites cause significant declines in both managed and native bee populations in North America. Honey bee colonies, both managed and feral, are being devastated by the external parasitic mite Varroa destructor that was introduced to the continent. As per the report by Thorp, R.W. (2003) the protozoan pathogen Nosema bombi caused great problems for reared colonies of the bumble bee Bombus occidentalis and has apparently lead to the wide scale declines of native B. occidentalis across the West Coast and also to declines in other bumble bees in the subgenus Bombus, particularly the eastern species B. affinis.

Pollinator Deficits and Commodity Prices

Pollinator deficits have multiple effects on the price of a commodity. In economic terms, the price of that commodity reflects the costs of production, distribution, and marketing plus profit. Thus pollinator deficits may increase the cost of production as the cost of providing pollinator services rises, owing to the greater demand for that service. Pollinator deficits may also cause a shift in the supply function, which may in turn result in a higher market price.

The economic impacts of pollinator deficits occur at various levels in the consumption-production continuum. At one extreme, there are the individuals who bear the brunt of the impact of pollinator deficits. For example, individual producers may experience a complete crop failure and resulting economic losses, or individual consumers may not be able to consume a particular commodity because pollinator deficits have made it unavailable. At the other extreme, there is the aggregate market, which may show little change in the total amount supplied by producers or demanded by consumers. In practice, a pollinator decline can be expected to affect both individuals and the market.

At the market level, basic economic theory considers a pollinator deficit that causes a reduction in production to be a shift in the supply function. This shifted supply function and the existing demand function lead to a new prevailing price. Normally the new price is higher than the original price, and the equilibrium quantity is less.

Valuation of Pollination Services

Putting a dollar figure on the value of pollination services may be important, if, as many researchers argue, financing conservation by determining economic value is an effective method for protecting ecosystem services. As per the report by Reid, W.V. (2001), attempts to create a mechanism for identifying an economic value for pollination services have been scarce in the U.S. this section lays out those existing economic arguments for valuing pollination services and then presents some additional indirect value considerations.

Economic Considerations

As per the report by Buchmann, S.L. (1996) worldwide, at least thirty percent of 1500 crop plant species depend on pollination by bees and other insects. Historically, the U.S. agricultural industry has depended heavily on the honey bee for its pollination needs. Consequently, most of the few existing studies that evaluate the economic importance of pollination services focus on agriculture and the honey bee. For example, Morse and Calderone estimate the value of agricultural crop production due to honey bee pollination was $14.6 billion in 2000. Morse and Calderone recognized that native pollinators made a significant contribution to crop values, but did not attempt to estimate this figure. A more recent study by Losey and Vaughan put a value of just over $3 billion on the pollination of U.S. fruits and vegetables by native insects.

The significance of pollinators to the agricultural industry is not the only aspect of pollination services that has economic value. In fact, pollination services can be linked to many other parts of present day economies. For example, most flowers use size and color to attract pollinators and humans have placed a high value on their uniqueness, beauty, and aroma. As a result, the production of cut flowers and potted plants for the florist trade, and use of plants for perfumes, shampoo and other cosmetics have developed into multinational industries that rely to some degree on the services of pollinators. As per the report by Allen-Wardell, G. et al. (1998) the pharmaceutical industry, cattle grazers, and people throughout the U.S. with small gardens in their backyards are also dependent upon and realize economic benefits from pollinators.

Non - Economic Considerations

Identifying economic value is not the only means for conveying the significance of pollination services and the relationships between pollinators and plants. With well over 200,000 flowering plant species dependent on pollination from over 100,000 pollinator species, pollination interactions have been a catalyst in developing, and are important to maintaining, the vast wealth of biodiversity on the planet. It is evident from the work of Kearns, C.A., D.W. Inouye, and N. Waser (1998) that pollination is a keystone process in both human-managed and natural terrestrial ecosystems. Without this service, many interconnected species inhabiting, and processes functioning within, an ecosystem would collapse. Flowers also produce the seeds and fruits that constitute the diets of many animal species. Pollinator declines can limit seed and fruit production and disrupt food supplies in natural communities. Pollinator-dependent plant communities help to bind the soil, reducing erosion that fouls creeks and impacts habitat for a wealth of aquatic life from salmon to mussels. Finally, pollinators have only recently been acknowledged for their contribution as consumers and distributors of energy-rich floral biomass. One study found that harvesting of plant primary production through collection of pollen, nectar, and resin by stingless social bees in Panama is greater than that of leafcutter ants, game animals, frugivores, vertebrate folivores, and insect defoliators excluding ants, and flower-feeding birds and bats.

Conclusions

It could be seen clearly from the above discussion that there is ample information to suggest the existence of pollinator declines that have affected, and are affecting, agricultural productivity. Threats to pollinators are pervasive. Researchers have presented evidence that pollination systems have been disrupted and some pollinator populations are declining. Clearly, measures must be taken to document the actual extent of pollinator declines, especially among the poorly studied native insect pollinators. Concurrent steps should be taken to avert a potential pollination crisis. It could be noted that no national strategy currently exists to deal with the pollinator declines, steps can be taken to strengthen and maintain efficient pollination systems. Some of the more notable approaches include. Improving agricultural practices and regulations that encourage, for example, targeted rather than broad-spectrum pesticides and the use of buffer strips. Restoring habitat and species through effective land use planning policies and adaptation of existing farm support programs. Reintroducing native plants and pollinators coupled with the removal of alien pollinators and valuing native diversity and promoting native gardens.

Scientific understanding of pollination dynamics and the consequences of diminishing pollinator levels is at best incomplete. Further research is needed to fill gaps in a wide array of pollination issues: the relationship between pollinators and plant populations, The effects of pesticides, grazing, logging, and suburban sprawl on native and feral pollinators, the importance of declining pollinator populations and the potential for cascading extinction, identifying pollinators on the World Conservation Union's endangered species list, competition among native and non native pollinator species and migratory dynamics of pollinators and pollinator specialization.

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